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# Proper Motions in the Region of NGC 3532

D. S. King

ABSTRACT. Relative proper motions of stars in the region of the galactic cluster NGC 3532 based on plates taken with the 33 cm astrograph, are determined with the aim of identifying stars in the area of the cluster which are non-members. The relative proper motions have an average standard error of 0".13/century and reveal 265 likely non-members and 382 likely members.

## INTRODUCTION

The open cluster NGC 3532 (R.A. = $11^h\ 02^m.2$, Dec. = $-58^\circ\ 08'$, 1900; $l$ = 257°.4, b = +1°.5) has been investigated photovisually by Martin (1933). The present investigation seeks to identify from their proper motions, those stars that are not members of the cluster.

## THE PLATES

The plates were taken with the 33 cm standard astrograph (scale 1' = 1 mm) as follows:

| | Plate No. | Date Taken | Exposure |
|---|---|---|---|
| 1 | 746s | 1893 Feb. 25 | 6 m |
| 2 | 746s | 1893 Feb. 25 | 3 m |
| 3 | 226RH | 1900 Mar. 8 | 3 m |
| 4 | 7530Sa | 1976 Apr. 20 | 16 m |
| 5 | 7546Sa | 1976 Apr. 30 | 10 m |
| 6 | 7622Sa | 1977 Mar. 17 | 3 m |

All plates are centred at R.A. $11^h\ 00^m$ Dec. $-58^\circ\ 00'$ (1900). The last three plates were taken through the glass.

## MEASUREMENT

The plates were bound together in pairs, one old and one new, film to film, three pairs being 1 - 4, 2 - 6, 3 - 5. The distances apart in x and y of the old and new images were measured in a short screw Repsold measuring machine adjusted to keep x and y parallel to the R.A. and Dec. axes. In addition, the plates 3 and 5 were measured in a Grubb-Parsons photoelectric measuring machine and the measures converted to the same system as the Repsold measured pairs. Each plate pair was measured twice in both direct and reverse with the average being recorded. All stars measured were selected from the published coordinates in the Astrographic Catalogue (Sydney Observatory 1954, plate N822) in the area between 6.0 - 18.0 in x and 37.0 - 46.0 in y. The plates were measured by Mrs. A. Brown, Miss J. Fitt, Miss D. Teale and Mr. D. King.

## REDUCTIONS AND PROBABILITIES

If $X_1$, $X_2$ are the measures of x on the new and old plates, $\mu$ is the annual proper motion and t is the time interval between the plates, then we can write:- $X_1 - X_2 = \mu t + ax + by + c + dm$ with a similar expression for $Y_1 - Y_2$ where x, y and m (magnitude) were taken from the Astrographic Catalogue. A least squares solution without the proper motion term was then obtained using all the stars measured. The solution was performed for each set of measures with a Diehl Alphatronic programmable calculator. Those stars whose residuals exceeded 2.5 times the standard deviation of the residuals were then eliminated from the solution and a further solution sought of the remaining stars. This was continued until the standard deviation of the residuals was comparable with the average standard error of the measurements. The resultant plate constants were then used to give the proper motions relative to the mean motion of the cluster. This is then converted to a centennial proper motion by multiplying by 100k/t where k is the scale factor to convert the measured differences to seconds of arc.

To determine the weight to be assigned to each of the plate pairs, the method of Sanders (1971) was used to determine the distribution parameters of a bivariate gaussian frequency function which would represent the calculated field and cluster star relative proper motions. The cluster star dispersion was assumed circular and its value was used as the weight of its corresponding plate pair. Thus, the weighted mean proper motions and standard errors were determined. The distribution parameters in arc sec./century after eliminating 16 stars with very large proper motions were:

$$\theta = 26^\circ \quad N_f = 249 \quad X_f = 0.025 \quad \Sigma_x = 0.557$$

$$\sigma_c = 0.161 \quad N_c = 382 \quad Y_f = -0.051 \quad \Sigma_y = 0.317$$

$\theta$ is the rotation angle of the observed proper motions ($+\mu_x$ to $+\mu_y$) into a new co-ordinate system defined by the principal axes of the apparent ellipsoidal distribution of field and cluster star motions. All the other parameters are defined in this new co-ordinate system. $\sigma_c$ is the dispersion of the cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars; $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions. These parameters were then used to determine a star's probability of membership.

The standard errors for individual stars have been grouped by their magnitudes, and the mean of the standard errors $\sigma_x$, $\sigma_y$ determined for different groups are as follows:-

| Magnitude | $\sigma_x$ | $\sigma_y$ | No. of stars |
|---|---|---|---|
| | (Unit 0".01/cent) | | |
| 10.7 - 11.0 | 15.4 | 14.7 | 251 |
| 10.0 - 10.6 | 12.0 | 13.0 | 144 |
| 9.0 - 9.9 | 11.5 | 11.9 | 173 |
| 7.5 - 8.9 | 13.6 | 13.3 | 79 |
| All | 13.35 | 13.42 | 647 |

An attempt at determining the absolute proper motion of the cluster by comparison with 26 Cape catalogue stars yielded -1.06 ± 0.17"/cent. in R.A. and +0.14 ± 0.21"/cent. in Dec.

The observational data follows in table 1. The various columns are:-

No. The number from the Astrographic Catalogue, Sydney Section ($11^h 00^m$ - $58^o$ centre).
Mag. The magnitude of the star as determined by the image diameter.
R.A.) Right ascension and declination, calculated
Dec.) from the astrographic place, brought to 1950.0.
CPD No.
V Photovisual magnitude from Martin.
$\mu_x,\mu_y$ Centennial proper motion in units of 0".01/cent. The axes are parallel to R.A. and Dec.
$\sigma_x,\sigma_y$ Standard errors of centennial proper motion in units of 0".01/cent.
P Probability of membership.
Notes 2 - only two plate pairs.
3 - three plate pairs.
5 - suspected eclipsing variable.
6 - not used in calculation of distribution parameters.

ACKNOWLEDGMENTS

I wish to thank W. H. Robertson for suggesting this research and for his constant encouragement and interest in this project. I would also like to thank the staff of Sydney Observatory who helped with the measuring and reduction.

REFERENCES

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Sanders, W.L., 1971. *Astronomy and Astrophysics*, *14*, 226 pp.
Sydney Observatory, 1954. *Astrographic Catalogue Sydney Section*, *26*, 94 pp.

TABLE 1

THE OBSERVATIONAL DATA

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 579 | 10.5 | 11 06 58 | -58 41 40 | | | -13 | -30 | 6 | 9 | 66 | |
| 580 | 10.8 | 11 06 57 | -58 43 17 | | | 51 | 2 | 27 | 17 | 13 | |
| 581 | 8.5 | 11 06 50 | -58 41 18 | $-58^o3199$ | | 0 | 26 | 13 | 18 | 81 | |
| 582 | 10.8 | 11 06 35 | -58 45 43 | | | 8 | -20 | 6 | 25 | 82 | |
| 583 | 10.8 | 11 06 34 | -58 43 13 | | | 60 | -45 | 13 | 27 | 0 | 3 |
| 584 | 7.5 | 11 06 27 | -58 42 17 | $-58^o3189$ | | 39 | 9 | 37 | 33 | 46 | |
| 586 | 10.7 | 11 06 18 | -58 42 39 | | | 41 | -23 | 13 | 23 | 17 | |
| 587 | 10.8 | 11 06 16 | -58 42 14 | | | 30 | -61 | 21 | 19 | 0 | |
| 588 | 10.5 | 11 06 12 | -58 42 56 | | | 32 | - 7 | 8 | 12 | 62 | |
| 589 | 10.6 | 11 06 12 | -58 43 40 | | | 101 | -30 | 7 | 11 | 0 | |
| 590 | 10.8 | 11 06 10 | -58 44 55 | | | 82 | -33 | 25 | 11 | 0 | |
| 591 | 10.7 | 11 06 09 | -58 41 35 | | | -31 | -16 | 17 | 19 | 59 | |
| 592 | 10.7 | 11 06 06 | -58 44 37 | | | - 1 | 0 | 11 | 15 | 91 | |
| 593 | 9.1 | 11 05 57 | -58 43 53 | $-58^o3175$ | | 5 | -42 | 21 | 20 | 36 | |
| 594 | 10.6 | 11 05 46 | -58 42 15 | | | 20 | -13 | 15 | 9 | 79 | |
| 595 | 10.5 | 11 05 29 | -58 43 10 | | | 9 | -24 | 24 | 10 | 77 | |
| 596 | 10.8 | 11 05 22 | -58 45 05 | | | 11 | 0 | 12 | 13 | 90 | |
| 597 | 10.7 | 11 05 20 | -58 42 44 | | | 15 | -39 | 16 | 4 | 35 | |
| 598 | 10.7 | 11 05 19 | -58 43 06 | | | 14 | - 5 | 16 | 28 | 88 | |
| 599 | 9.5 | 11 05 11 | -58 41 59 | $-58^o3153$ | | - 5 | - 3 | 8 | 22 | 91 | |
| 600 | 10.8 | 11 05 08 | -58 45 42 | | | 39 | - 4 | 15 | 19 | 44 | 3 |
| 601 | 10.8 | 11 04 49 | -58 45 58 | | | -10 | 12 | 5 | 23 | 88 | |
| 602 | 9.7 | 11 04 02 | -58 45 55 | $-58^o3098$ | | - 1 | -27 | 23 | 15 | 76 | |
| 603 | 10.8 | 11 03 57 | -58 45 20 | | | -25 | 1 | 11 | 23 | 78 | |
| 604 | 10.8 | 11 03 55 | -58 44 34 | | | -60 | -58 | 28 | 28 | 0 | |
| 605 | 10.8 | 11 03 43 | -58 45 11 | | | 23 | 6 | 13 | 9 | 82 | |
| 606 | 10.8 | 11 03 41 | -58 45 20 | | | 23 | -24 | 18 | 11 | 59 | |
| 607 | 10.5 | 11 03 41 | -58 44 05 | | | 0 | -12 | 10 | 20 | 89 | |
| 608 | 9.5 | 11 03 35 | -58 41 35 | $-58^o3076$ | 10.26 | 13 | -12 | 11 | 23 | 86 | |
| 609 | 10.8 | 11 03 32 | -58 44 24 | | | 43 | -43 | 3 | 30 | 2 | 3 |
| 610 | 10.3 | 11 03 22 | -58 43 49 | | | -24 | 8 | 16 | 10 | 78 | |
| 611 | 9.5 | 11 03 14 | -58 46 00 | $-58^o3060$ | | - 7 | - 3 | 14 | 19 | 90 | |
| 612 | 10.1 | 11 03 14 | -58 42 34 | $-58^o3061$ | | -20 | 13 | 7 | 19 | 80 | |
| 613 | 10.8 | 11 03 02 | -58 42 31 | | | 178 | -78 | 17 | 9 | 0 | 3 |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 614 | 8.5 | 11 03 00 | -58 44 48 | $-58^{\circ}3048$ | | 5 | -19 | 3 | 13 | 84 | |
| 615 | 10.1 | 11 03 00 | -58 43 12 | $-58^{\circ}3047$ | | 32 | -27 | 8 | 7 | 32 | |
| 616 | 10.8 | 11 02 54 | -58 45 27 | | | 4 | -21 | 6 | 25 | 83 | |
| 617 | 7.8 | 11 02 52 | -58 44 54 | $-58^{\circ}3039$ | | - 2 | - 9 | 23 | 12 | 90 | |
| 618 | 9.7 | 11 02 43 | -58 42 34 | $-58^{\circ}3033$ | 10.76 | 24 | - 4 | 17 | 4 | 79 | |
| 619 | 10.1 | 11 02 38 | -58 42 14 | $-58^{\circ}3029$ | | 6 | 10 | 21 | 11 | 90 | |
| 620 | 10.8 | 11 02 30 | -58 42 49 | | | -15 | 11 | 16 | 17 | 86 | |
| 621 | 10.5 | 11 02 26 | -58 45 18 | | | 9 | -57 | 4 | 25 | 5 | |
| 622 | 10.1 | 11 02 25 | -58 45 40 | | | -26 | -17 | 10 | 34 | 68 | |
| 623 | 10.8 | 11 02 22 | -58 44 16 | | | 8 | -44 | 15 | 22 | 28 | |
| 624 | 10.3 | 11 02 17 | -58 44 06 | $-58^{\circ}3008$ | | -56 | -21 | 21 | 8 | 3 | |
| 625 | 10.3 | 11 02 08 | -58 43 22 | | | 3 | - 4 | 6 | 7 | 91 | |
| 626 | 9.5 | 11 01 47 | -58 45 45 | $-58^{\circ}2996$ | | 27 | -30 | 7 | 9 | 37 | |
| 628 | 10.8 | 11 01 36 | -58 42 51 | | | 76 | -61 | 26 | 20 | 0 | 3 |
| 629 | 10.5 | 11 01 34 | -58 42 28 | | | -201 | 107 | 8 | 16 | 0 | 6 |
| 630 | 10.9 | 11 01 33 | -58 42 36 | | | 58 | -41 | 16 | 13 | 0 | 3 |
| 631 | 9.7 | 11 01 15 | -58 42 57 | $-58^{\circ}2984$ | | - 8 | -30 | 12 | 8 | 69 | |
| 632 | 8.9 | 11 01 12 | -58 45 50 | $-58^{\circ}2981$ | | 13 | -34 | 12 | 27 | 52 | |
| 633 | 9.7 | 11 01 10 | -58 43 44 | $-58^{\circ}2980$ | | - 4 | -23 | 13 | 8 | 81 | |
| 634 | 9.7 | 11 00 32 | -58 44 51 | $-58^{\circ}2961$ | | -40 | -16 | 8 | 14 | 33 | |
| 635 | 10.8 | 11 00 25 | -58 44 44 | | | - 8 | - 2 | 11 | 12 | 90 | |
| 637 | 10.8 | 10 59 42 | -58 44 36 | | | 14 | 0 | 8 | 18 | 89 | |
| 688 | 10.7 | 11 07 01 | -58 40 55 | | | 60 | -27 | 11 | 10 | 0 | |
| 689 | 10.7 | 11 06 30 | -58 40 28 | | | 113 | -29 | 19 | 13 | 0 | |
| 690 | 9.3 | 11 06 24 | -58 39 30 | $-58^{\circ}3188$ | | - 2 | -25 | 11 | 16 | 79 | |
| 691 | 10.3 | 11 06 24 | -58 40 54 | | | - 5 | - 6 | 23 | 11 | 90 | |
| 692 | 8.2 | 11 06 20 | -58 37 04 | $-58^{\circ}3186$ | | 18 | -21 | 25 | 27 | 73 | |
| 693 | 8.5 | 11 06 07 | -58 40 14 | $-58^{\circ}3178$ | | 19 | -36 | 15 | 5 | 37 | |
| 695 | 10.1 | 11 05 43 | -58 37 35 | $-58^{\circ}3171$ | 11.35 | -72 | -32 | 22 | 9 | 0 | |
| 696 | 9.1 | 11 05 42 | -58 41 00 | $-58^{\circ}3168$ | 10.26 | -21 | -11 | 9 | 16 | 80 | |
| 697 | 9.7 | 11 05 38 | -58 36 44 | $-58^{\circ}3166$ | 10.60 | -10 | -16 | 13 | 16 | 85 | |
| 698 | 10.8 | 11 05 29 | -58 40 44 | | | -11 | 34 | 12 | 8 | 62 | 3 |
| 699 | 8.0 | 11 05 03 | -58 38 12 | $-58^{\circ}3147$ | 8.36 | 8 | - 8 | 13 | 7 | 89 | |
| 700 | 10.8 | 11 04 50 | -58 38 15 | | | 85 | 16 | 13 | 27 | 0 | 3 |
| 701 | 10.5 | 11 04 49 | -58 37 33 | | | 22 | -35 | 9 | 16 | 35 | |
| 702 | 10.5 | 11 04 48 | -58 37 16 | | | 13 | -64 | 9 | 10 | 1 | |
| 703 | 9.9 | 11 04 43 | -58 36 55 | $-58^{\circ}3130$ | 11.08 | 4 | -37 | 9 | 8 | 52 | |
| 704 | 10.8 | 11 04 31 | -58 40 00 | | | 2 | 14 | 10 | 14 | 89 | |
| 705 | 10.8 | 11 04 31 | -58 39 45 | | | -12 | 0 | 20 | 10 | 89 | 3 |
| 706 | 10.8 | 11 04 27 | -58 37 47 | | | -26 | -24 | 23 | 14 | 59 | |
| 707 | 9.1 | 11 04 27 | -58 38 59 | $-58^{\circ}3119$ | 9.87 | 8 | -33 | 15 | 18 | 60 | |
| 708 | 10.7 | 11 04 17 | -58 37 06 | | | 3 | 19 | 7 | 32 | 87 | |
| 710 | 10.7 | 11 04 08 | -58 36 42 | | | -14 | 62 | 18 | 22 | 3 | 3 |
| 711 | 10.3 | 11 04 03 | -58 40 15 | | 11.39 | 52 | 44 | 30 | 17 | 1 | |
| 712 | 8.2 | 11 04 00 | -58 37 18 | $-58^{\circ}3097$ | 8.51 | -18 | 4 | 12 | 9 | 85 | |
| 713 | 10.8 | 11 03 58 | -58 41 23 | | | -49 | -53 | 10 | 18 | 0 | |
| 714 | 10.8 | 11 03 58 | -58 39 52 | | | -15 | 15 | 12 | 13 | 84 | |
| 715 | 10.8 | 11 03 57 | -58 40 15 | | | 59 | - 9 | 13 | 10 | 2 | 3 |
| 716 | 10.1 | 11 03 52 | -58 37 03 | $-58^{\circ}3091$ | 11.08 | 9 | -12 | 7 | 5 | 87 | |
| 717 | 10.5 | 11 03 51 | -58 40 21 | | | -33 | 0 | 9 | 13 | 61 | |
| 718 | 10.8 | 11 03 47 | -58 37 50 | | | 14 | - 5 | 13 | 21 | 88 | |
| 719 | 10.8 | 11 03 45 | -58 39 21 | | | -23 | - 5 | 13 | 13 | 80 | |
| 720 | 10.7 | 11 03 43 | -58 40 35 | | | -10 | -25 | 28 | 10 | 77 | |
| 721 | 10.5 | 11 03 42 | -58 40 08 | | 11.53 | -20 | 11 | 5 | 13 | 81 | |
| 722 | 10.6 | 11 03 29 | -58 36 50 | | 11.60 | -17 | 13 | 15 | 23 | 83 | 3 |
| 723 | 10.8 | 11 03 29 | -58 41 07 | | | -36 | - 1 | 19 | 29 | 53 | |
| 724 | 10.1 | 11 03 26 | -58 38 25 | $-58^{\circ}3067$ | 11.08 | 0 | 1 | 8 | 5 | 91 | |
| 725 | 10.8 | 11 03 24 | -58 40 02 | | | 38 | -70 | 11 | 21 | 0 | |
| 726 | 9.5 | 11 03 19 | -58 39 07 | $-58^{\circ}3065$ | 10.30 | 19 | -32 | 21 | 6 | 48 | |
| 727 | 9.9 | 11 02 58 | -58 38 22 | $-58^{\circ}3045$ | 10.71 | - 1 | - 4 | 7 | 15 | 91 | |
| 728 | 10.7 | 11 02 56 | -58 37 56 | | | -22 | - 9 | 13 | 13 | 80 | |
| 729 | 10.5 | 11 02 55 | -58 38 52 | | 11.07 | -257 | -215 | 11 | 9 | 0 | 6 |
| 730 | 10.3 | 11 02 54 | -58 40 40 | | | - 4 | 5 | 9 | 16 | 91 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 731 | 10.9 | 11 02 53 | -58 40 08 | | | - 4 | - 8 | 20 | 23 | 90 | 3 |
| 732 | 10.7 | 11 02 50 | -58 40 16 | | | -29 | 30 | 21 | 28 | 37 | |
| 733 | 10.7 | 11 02 49 | -58 37 35 | | | -48 | 20 | 21 | 13 | 9 | |
| 734 | 10.3 | 11 02 49 | -58 39 21 | | 11.08 | -12 | 17 | 9 | 16 | 84 | |
| 735 | 10.8 | 11 02 45 | -58 37 49 | | | 3 | - 1 | 22 | 9 | 91 | |
| 736 | 10.8 | 11 02 43 | -58 39 47 | | | -100 | 29 | 15 | 1 | 0 | |
| 737 | 9.9 | 11 02 35 | -58 41 06 | $-58^{o}3024$ | 11.06 | - 4 | 13 | 14 | 13 | 89 | |
| 738 | 10.7 | 11 02 35 | -58 40 35 | | | -53 | 14 | 14 | 18 | 5 | |
| 739 | 9.5 | 11 02 16 | -58 38 56 | $-58^{o}3006$ | 10.21 | 3 | 8 | 4 | 12 | 91 | |
| 740 | 10.5 | 11 02 16 | -58 39 41 | | 10.70 | -12 | -39 | 11 | 10 | 44 | |
| 741 | 10.6 | 11 02 09 | -58 41 18 | | | -16 | 18 | 18 | 18 | 81 | |
| 742 | 10.5 | 11 01 59 | -58 38 20 | | | 51 | -34 | 7 | 8 | 1 | |
| 743 | 9.7 | 11 01 49 | -58 39 50 | $-58^{o}2997$ | 10.34 | 17 | 26 | 9 | 6 | 76 | |
| 744 | 10.7 | 11 01 48 | -58 39 56 | | | 1 | -24 | 14 | 9 | 80 | |
| 745 | 10.8 | 11 01 14 | -58 41 15 | | | 9 | 15 | 17 | 15 | 88 | |
| 746 | 10.7 | 11 01 12 | -58 39 46 | | | 3 | 49 | 17 | 11 | 28 | |
| 747 | 8.5 | 11 01 06 | -58 37 21 | $-58^{o}2979$ | | -18 | 8 | 13 | 12 | 84 | |
| 748 | 10.8 | 11 01 03 | -58 37 43 | | | -38 | - 7 | 6 | 20 | 45 | |
| 749 | 10.3 | 11 00 52 | -58 41 14 | | | - 4 | 11 | 15 | 17 | 90 | |
| 750 | 10.8 | 11 00 52 | -58 39 48 | | | -69 | 152 | 11 | 15 | 0 | 6 |
| 751 | 10.8 | 11 00 52 | -58 39 23 | | | -21 | 10 | 15 | 14 | 81 | |
| 752 | 10.1 | 11 00 50 | -58 38 18 | $-58^{o}2972$ | | - 6 | 3 | 18 | 24 | 91 | |
| 753 | 10.3 | 11 00 41 | -58 36 36 | $-58^{o}2966$ | | -24 | 34 | 10 | 11 | 40 | |
| 754 | 9.5 | 11 00 39 | -58 38 24 | $-58^{o}2964$ | | -23 | 2 | 15 | 14 | 80 | |
| 755 | 10.8 | 11 00 37 | -58 38 00 | | | 29 | - 3 | 19 | 13 | 72 | |
| 756 | 10.7 | 11 00 21 | -58 39 02 | | | 15 | 1 | 4 | 12 | 88 | |
| 757 | 10.7 | 11 00 20 | -58 39 07 | | | 28 | - 1 | 20 | 18 | 74 | |
| 758 | 10.3 | 11 00 14 | -58 40 28 | | | 1 | 24 | 15 | 26 | 84 | |
| 759 | 10.8 | 11 00 10 | -58 38 16 | | | -174 | 43 | 14 | 21 | 0 | |
| 760 | 10.5 | 10 59 56 | -58 41 03 | | | 72 | -29 | 13 | 25 | 0 | |
| 761 | 10.6 | 10 59 51 | -58 39 26 | | | -13 | 42 | 6 | 15 | 37 | |
| 810 | 10.8 | 11 07 05 | -58 32 18 | | | -36 | 24 | 20 | 20 | 30 | |
| 811 | 10.8 | 11 07 03 | -58 34 27 | | | - 1 | 11 | 23 | 19 | 90 | |
| 812 | 10.8 | 11 07 00 | -58 33 48 | | | 33 | -19 | 15 | 6 | 44 | |
| 813 | 8.7 | 11 06 45 | -58 33 35 | $-58^{o}3198$ | | 1 | 10 | 8 | 15 | 91 | |
| 814 | 9.3 | 11 06 42 | -58 34 47 | $-58^{o}3197$ | | 6 | -31 | 12 | 16 | 66 | |
| 815 | 9.7 | 11 06 35 | -58 32 07 | $-58^{o}3194$ | | -23 | 27 | 7 | 8 | 58 | |
| 816 | 8.5 | 11 06 16 | -58 33 19 | $-58^{o}3183$ | | - 4 | -34 | 15 | 16 | 62 | |
| 817 | 10.8 | 11 06 11 | -58 33 54 | | | 14 | -51 | 32 | 29 | 9 | 3 |
| 818 | 9.9 | 11 06 07 | -58 34 02 | $-58^{o}3179$ | | 27 | 19 | 9 | 9 | 70 | |
| 819 | 10.7 | 11 05 56 | -58 33 00 | | | 1 | 21 | 7 | 8 | 86 | |
| 820 | 8.7 | 11 05 51 | -58 34 42 | $-58^{o}3174$ | | -13 | 7 | 16 | 12 | 88 | |
| 821 | 9.1 | 11 05 43 | -58 33 32 | $-58^{o}3170$ | 10.14 | - 5 | 7 | 9 | 11 | 91 | |
| 822 | 9.7 | 11 05 41 | -58 35 32 | $-58^{o}3167$ | 10.96 | 13 | - 2 | 6 | 17 | 89 | |
| 823 | 10.1 | 11 05 37 | -58 36 11 | $-58^{o}3164$ | | 16 | -18 | 7 | 8 | 79 | |
| 824 | 10.8 | 11 05 26 | -58 35 25 | | | 159 | -141 | 14 | 29 | 0 | 6 |
| 825 | 10.3 | 11 05 21 | -58 31 39 | | 11.40 | -16 | 5 | 17 | 17 | 87 | |
| 826 | 10.3 | 11 05 21 | -58 36 14 | | 10.56 | 160 | 95 | 9 | 12 | 0 | 6 |
| 827 | 10.6 | 11 05 20 | -58 35 06 | | | 29 | -40 | 17 | 9 | 13 | |
| 828 | 10.8 | 11 05 14 | -58 32 43 | | | 39 | 23 | 23 | 9 | 35 | |
| 829 | 9.9 | 11 05 13 | -58 32 00 | $-58^{o}3154$ | 10.96 | -31 | - 4 | 16 | 5 | 66 | |
| 830 | 10.1 | 11 05 09 | -58 34 24 | $-58^{o}3152$ | 11.00 | - 2 | 26 | 8 | 13 | 81 | |
| 831 | 10.6 | 11 05 08 | -58 35 41 | | 11.06 | 0 | 31 | 9 | 10 | 75 | |
| 832 | 10.1 | 11 05 05 | -58 35 00 | $-58^{o}3148$ | 10.86 | -26 | 40 | 8 | 4 | 22 | |
| 833 | 10.7 | 11 05 03 | -58 36 15 | | | 30 | -27 | 12 | 12 | 36 | |
| 834 | 9.1 | 11 05 03 | -58 32 40 | $-58^{o}3145$ | 9.68 | - 5 | 1 | 7 | 17 | 91 | |
| 835 | 9.1 | 11 04 54 | -58 33 38 | $-58^{o}3138$ | 9.84 | 2 | 22 | 9 | 12 | 85 | |
| 836 | 9.5 | 11 04 49 | -58 33 05 | $-58^{o}3134$ | 10.21 | - 1 | 13 | 11 | 16 | 90 | |
| 837 | 9.5 | 11 04 35 | -58 31 56 | $-58^{o}3125$ | 10.24 | 4 | 0 | 3 | 12 | 91 | |
| 838 | 8.9 | 11 04 30 | -58 35 25 | $-58^{o}3123$ | 9.59 | -16 | - 2 | 7 | 4 | 87 | |
| 839 | 10.3 | 11 04 27 | -58 34 27 | $-58^{o}3118$ | 11.18 | -18 | 13 | 6 | 10 | 82 | |
| 840 | 8.7 | 11 04 21 | -58 32 04 | $-58^{o}3114$ | 8.81 | 20 | -28 | 17 | 9 | 56 | |
| 841 | 10.8 | 11 04 15 | -58 33 37 | | | 14 | 52 | 16 | 20 | 18 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 842 | 10.8 | 11 04 07 | -58 32 49 | | | 29 | -38 | 6 | 3 | 16 | |
| 843 | 8.5 | 11 04 06 | -58 32 23 | $-58^{\circ}3104$ | 8.84 | -35 | -10 | 15 | 24 | 53 | |
| 844 | 8.2 | 11 04 06 | -58 34 25 | $-58^{\circ}3103$ | 8.06 | 30 | - 5 | 25 | 13 | 68 | |
| 845 | 10.8 | 11 04 01 | -58 32 50 | | | 17 | 31 | 7 | 8 | 68 | 3 |
| 846 | 9.9 | 11 03 59 | -58 35 56 | $-58^{\circ}3095$ | 10.90 | -19 | 11 | 18 | 11 | 82 | |
| 847 | 10.8 | 11 03 54 | -58 34 11 | | | -12 | 0 | 18 | 19 | 89 | |
| 848 | 9.7 | 11 03 49 | -58 32 55 | $-58^{\circ}3086$ | 9.05 | - 1 | 35 | 5 | 7 | 67 | |
| 849 | 9.1 | 11 03 48 | -58 32 47 | | 9.76 | -18 | 35 | 17 | 9 | 49 | |
| 850 | 10.8 | 11 03 47 | -58 32 10 | | | 61 | - 1 | 17 | 24 | 2 | |
| 851 | 10.1 | 11 03 45 | -58 34 35 | $-58^{\circ}3084$ | 11.06 | -10 | 21 | 9 | 8 | 83 | |
| 852 | 8.5 | 11 03 41 | -58 33 38 | $-58^{\circ}3079$ | 9.06 | - 4 | 23 | 4 | 13 | 84 | |
| 853 | 8.7 | 11 03 35 | -58 33 56 | $-58^{\circ}3075$ | 8.82 | - 4 | 1 | 14 | 9 | 91 | |
| 854 | 10.8 | 11 03 34 | -58 32 21 | | | 27 | -39 | 12 | 9 | 17 | |
| 855 | 10.8 | 11 03 30 | -58 32 27 | | | 50 | -31 | 21 | 17 | 2 | |
| 856 | 10.8 | 11 03 30 | -58 35 45 | | 11.69 | -49 | 13 | 7 | 16 | 10 | |
| 857 | 10.8 | 11 03 29 | -58 35 59 | | | 12 | 34 | 26 | 15 | 66 | |
| 858 | 10.8 | 11 03 26 | -58 34 53 | | | - 1 | 23 | 3 | 11 | 84 | |
| 859 | 10.6 | 11 03 20 | -58 35 26 | | 11.38 | - 7 | 31 | 18 | 9 | 72 | |
| 860 | 10.8 | 11 03 18 | -58 34 51 | | | -17 | -22 | 19 | 10 | 75 | |
| 861 | 9.7 | 11 03 16 | -58 34 21 | $-58^{\circ}3063$ | 10.44 | - 1 | 4 | 12 | 6 | 91 | |
| 862 | 10.1 | 11 03 12 | -58 32 54 | $-58^{\circ}3059$ | 11.30 | 21 | -27 | 6 | 10 | 57 | |
| 863 | 8.5 | 11 03 06 | -58 34 21 | $-58^{\circ}3053$ | 9.26 | 8 | 10 | 5 | 6 | 90 | |
| 864 | 9.7 | 11 03 05 | -58 35 40 | $-58^{\circ}3051$ | 9.48 | 21 | 15 | 11 | 5 | 81 | |
| 865 | 9.1 | 11 03 01 | -58 35 24 | $-58^{\circ}3050$ | 9.60 | -26 | -24 | 16 | 11 | 59 | |
| 866 | 9.1 | 11 02 53 | -58 33 40 | $-58^{\circ}3041$ | 9.92 | 11 | 17 | 3 | 25 | 87 | |
| 867 | 8.9 | 11 02 53 | -58 31 58 | $-58^{\circ}3040$ | 9.36 | 5 | 3 | 12 | 16 | 91 | |
| 868 | 8.2 | 11 02 51 | -58 31 31 | $-58^{\circ}3038$ | 8.31 | 5 | 12 | 8 | 29 | 90 | |
| 869 | 10.3 | 11 02 42 | -58 35 35 | | 11.11 | -508 | -65 | 7 | 9 | 0 | 6 |
| 870 | 10.8 | 11 02 38 | -58 33 56 | | | 72 | -42 | 21 | 19 | 0 | |
| 871 | 10.6 | 11 02 35 | -58 32 01 | | | 19 | -40 | 6 | 19 | 27 | |
| 872 | 10.8 | 11 02 33 | -58 33 09 | | | -64 | 14 | 18 | 10 | 1 | |
| 873 | 10.8 | 11 02 33 | -58 33 28 | | | 8 | 21 | 16 | 10 | 85 | |
| 874 | 9.5 | 11 02 32 | -58 33 17 | $-58^{\circ}3020$ | 9.76 | -13 | 31 | 4 | 8 | 66 | |
| 875 | 9.5 | 11 02 29 | -58 32 23 | $-58^{\circ}3015$ | 10.35 | 8 | 15 | 6 | 9 | 88 | |
| 876 | 10.7 | 11 02 27 | -58 31 57 | | | 25 | -14 | 8 | 15 | 71 | |
| 877 | 9.1 | 11 02 24 | -58 35 35 | $-58^{\circ}3011$ | 9.93 | 3 | - 5 | 5 | 8 | 91 | |
| 878 | 10.8 | 11 02 21 | -58 33 12 | | 11.58 | -61 | 57 | 25 | 16 | 0 | |
| 879 | 10.7 | 11 02 18 | -58 34 11 | | | -27 | 26 | 8 | 19 | 50 | |
| 880 | 10.8 | 11 02 16 | -58 32 46 | | | -56 | -16 | 23 | 10 | 4 | |
| 881 | 10.8 | 11 02 10 | -58 33 48 | | 11.58 | 0 | 32 | 16 | 12 | 73 | |
| 882 | 9.7 | 11 02 09 | -58 32 45 | $-58^{\circ}3004$ | 10.76 | 6 | 19 | 28 | 10 | 87 | |
| 883 | 10.8 | 11 02 08 | -58 35 47 | | | -97 | 78 | 16 | 19 | 0 | |
| 884 | 9.5 | 11 02 01 | -58 34 35 | $-58^{\circ}3002$ | 9.94 | - 2 | 36 | 12 | 7 | 64 | |
| 885 | 10.7 | 11 01 59 | -58 35 21 | | | 0 | 19 | 15 | 8 | 87 | |
| 886 | 9.1 | 11 01 55 | -58 36 06 | $-58^{\circ}3000$ | 9.67 | - 6 | 10 | 8 | 12 | 90 | |
| 887 | 10.8 | 11 01 55 | -58 35 33 | | | 4 | 0 | 21 | 13 | 91 | |
| 888 | 9.1 | 11 01 50 | -58 35 27 | $-58^{\circ}2999$ | 9.55 | 57 | -23 | 13 | 8 | 1 | |
| 889 | 10.1 | 11 01 49 | -58 31 43 | $-58^{\circ}2998$ | 10.90 | -31 | 17 | 20 | 12 | 55 | |
| 890 | 10.8 | 11 01 43 | -58 32 03 | | | 4 | 32 | 5 | 6 | 73 | |
| 891 | 10.5 | 11 01 42 | -58 32 33 | | | - 6 | 12 | 19 | 10 | 89 | |
| 892 | 10.5 | 11 01 33 | -58 33 35 | | | 26 | 1 | 3 | 9 | 78 | |
| 893 | 10.8 | 11 00 58 | -58 36 00 | | | 35 | - 5 | 15 | 17 | 56 | |
| 894 | 10.7 | 11 00 46 | -58 34 54 | | | - 5 | -39 | 17 | 19 | 48 | |
| 895 | 10.6 | 11 00 41 | -58 34 48 | | | 7 | -10 | 15 | 7 | 89 | |
| 896 | 10.6 | 11 00 40 | -58 35 27 | | | -17 | 8 | 8 | 8 | 85 | |
| 897 | 8.9 | 11 00 38 | -58 32 59 | $-58^{\circ}2963$ | | 33 | -21 | 5 | 14 | 41 | |
| 898 | 9.7 | 11 00 04 | -58 33 53 | $-58^{\circ}2948$ | | -16 | 30 | 4 | 22 | 64 | |
| 899 | 10.3 | 10 59 52 | -58 33 37 | | | - 8 | -22 | 8 | 13 | 81 | |
| 900 | 9.7 | 10 59 35 | -58 33 36 | $-58^{\circ}2943$ | | 5 | -139 | 11 | 21 | 0 | |
| 948 | 7.8 | 11 07 02 | -58 27 11 | $-58^{\circ}3203$ | | 3 | 24 | 19 | 16 | 84 | |
| 949 | 10.7 | 11 06 52 | -58 30 42 | | | 84 | -41 | 18 | 13 | 0 | |
| 950 | 10.7 | 11 06 42 | -58 27 28 | | | 15 | -13 | 28 | 23 | 84 | |
| 951 | 9.9 | 11 06 36 | -58 31 10 | $-58^{\circ}3195$ | | 5 | 39 | 10 | 11 | 57 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 952 | 9.5 | 11 06 34 | -58 26 23 | -58°3193 | | -21 | - 2 | 10 | 9 | 83 | |
| 953 | 10.7 | 11 06 23 | -58 31 12 | | | 27 | - 5 | 14 | 12 | 74 | |
| 954 | 10.8 | 11 06 22 | -58 27 04 | | | 49 | 0 | 12 | 4 | 16 | 3 |
| 955 | 10.8 | 11 06 06 | -58 30 15 | | | 53 | - 4 | 5 | 10 | 8 | |
| 956 | 9.5 | 11 06 02 | -58 27 39 | -58°3177 | | 2 | 58 | 7 | 17 | 9 | |
| 957 | 10.8 | 11 06 00 | -58 28 18 | | | - 2 | 42 | 16 | 15 | 48 | |
| 958 | 9.9 | 11 05 43 | -58 27 56 | -58°3169 | | 4 | 19 | 2 | 7 | 87 | |
| 959 | 10.8 | 11 05 41 | -58 26 23 | | | 43 | 25 | 14 | 19 | 22 | |
| 960 | 9.9 | 11 05 38 | -58 29 22 | | 11.20 | 1 | 13 | 3 | 13 | 90 | 3 |
| 961 | 10.3 | 11 05 37 | -58 26 39 | -58°3162 | | - 6 | -17 | 11 | 23 | 86 | |
| 962 | 10.8 | 11 05 36 | -58 26 45 | | | -40 | 33 | 22 | 34 | 10 | 3 |
| 963 | 10.8 | 11 05 36 | -58 27 08 | | 11.58 | 15 | -27 | 17 | 10 | 66 | |
| 964 | 8.2 | 11 05 34 | -58 29 09 | -58°3161 | 8.64 | -29 | -22 | 19 | 12 | 56 | |
| 965 | 9.5 | 11 05 30 | -58 31 08 | -58°3160 | 10.20 | -17 | 24 | 6 | 19 | 73 | |
| 966 | 10.7 | 11 05 10 | -58 29 46 | | | 16 | 3 | 11 | 20 | 88 | |
| 967 | 10.6 | 11 05 04 | -58 26 56 | | 11.70 | 8 | 14 | 9 | 11 | 89 | 2 |
| 968 | 9.5 | 11 05 02 | -58 29 26 | -58°3146 | 10.48 | -19 | -13 | 9 | 19 | 81 | |
| 969 | 8.0 | 11 05 00 | -58 26 45 | -58°3144 | 8.42 | -23 | -14 | 13 | 16 | 76 | |
| 970 | 10.8 | 11 04 59 | -58 28 39 | | | 6 | 30 | 12 | 13 | 76 | |
| 971 | 9.9 | 11 04 58 | -58 29 05 | -58°3143 | 10.40 | -163 | 34 | 14 | 8 | 0 | |
| 972 | 9.5 | 11 04 56 | -58 30 02 | -58°3142 | 10.18 | -12 | - 5 | 11 | 18 | 89 | |
| 973 | 9.3 | 11 04 53 | -58 26 30 | -58°3139 | 9.65 | -14 | -41 | 11 | 12 | 37 | |
| 974 | 9.9 | 11 04 53 | -58 30 50 | -58°3137 | 10.82 | 31 | 0 | 13 | 7 | 68 | |
| 975 | 9.5 | 11 04 52 | -58 29 32 | -58°3136 | 10.15 | 9 | 5 | 7 | 11 | 90 | |
| 976 | 9.3 | 11 04 47 | -58 29 56 | -58°3133 | 9.81 | -11 | 0 | 4 | 10 | 89 | |
| 977 | 7.8 | 11 04 47 | -58 31 22 | -58°3132 | 7.45 | 10 | 3 | 25 | 9 | 90 | |
| 978 | 10.8 | 11 04 45 | -58 28 44 | | | -79 | -68 | 9 | 12 | 0 | |
| 979 | 8.5 | 11 04 41 | -58 28 19 | -58°3128 | 8.70 | 11 | 14 | 10 | 18 | 88 | |
| 980 | 10.1 | 11 04 38 | -58 31 20 | -58°3127 | 10.92 | 68 | -19 | 11 | 10 | 0 | |
| 981 | 7.8 | 11 04 28 | -58 28 25 | -58°3120 | 7.81 | -38 | 3 | 14 | 9 | 46 | |
| 982 | 10.8 | 11 04 21 | -58 28 47 | | | -34 | 37 | 14 | 13 | 14 | |
| 983 | 8.7 | 11 04 20 | -58 29 34 | -58°3110 | 9.01 | - 9 | - 9 | 14 | 17 | 89 | |
| 984 | 9.5 | 11 04 13 | -58 28 40 | -58°3106 | 9.83 | 10 | 25 | 23 | 13 | 81 | |
| 985 | 10.3 | 11 04 08 | -58 30 48 | -58°3105 | 11.05 | 8 | 15 | 15 | 12 | 88 | |
| 986 | 8.5 | 11 04 05 | -58 28 03 | -58°3102 | 8.48 | -30 | -12 | 9 | 19 | 65 | |
| 987 | 9.7 | 11 04 04 | -58 28 45 | -58°3100 | 10.46 | - 9 | 25 | 6 | 7 | 79 | |
| 988 | 9.7 | 11 04 04 | -58 29 45 | -58°3101 | 10.53 | 1 | 11 | 9 | 18 | 90 | |
| 989 | 10.6 | 11 04 03 | -58 30 59 | | 11.75 | -28 | 16 | 19 | 16 | 64 | |
| 990 | 10.8 | 11 04 01 | -58 29 38 | | | -50 | 45 | 13 | 10 | 0 | |
| 991 | 10.7 | 11 04 01 | -58 27 14 | | | -40 | 42 | 6 | 17 | 4 | |
| 992 | 10.8 | 11 03 58 | -58 28 57 | | | 0 | 21 | 6 | 16 | 86 | |
| 993 | 8.2 | 11 03 51 | -58 27 16 | -58°3090 | 7.79 | 23 | 31 | 10 | 24 | 60 | |
| 994 | 9.5 | 11 03 50 | -58 27 55 | -58°3089 | 10.12 | -10 | 14 | 10 | 19 | 87 | |
| 995 | 10.8 | 11 03 44 | -58 30 39 | | | -32 | -25 | 25 | 22 | 43 | 3 |
| 996 | 8.7 | 11 03 44 | -58 27 40 | -58°3081 | 9.30 | 8 | 18 | 5 | 15 | 87 | |
| 997 | 10.8 | 11 03 42 | -58 29 48 | | | - 9 | 20 | 9 | 13 | 84 | |
| 998 | 10.8 | 11 03 40 | -58 30 01 | | | -13 | 3 | 18 | 15 | 89 | |
| 999 | 10.5 | 11 03 36 | -58 28 00 | -58°3074 | 11.36 | 1 | -21 | 24 | 6 | 83 | 3 |
| 1000 | 8.5 | 11 03 33 | -58 27 40 | -58°3073 | 8.68 | 6 | 21 | 8 | 10 | 86 | |
| 1001 | 9.9 | 11 03 32 | -58 31 10 | -58°3072 | 10.33 | -745 | 340 | 12 | 17 | 0 | 6 |
| 1002 | 9.3 | 11 03 31 | -58 29 37 | -58°3070 | 9.65 | 50 | 0 | 18 | 8 | 14 | |
| 1003 | 9.5 | 11 03 30 | -58 29 10 | -58°3071 | 9.91 | 9 | - 6 | 4 | 9 | 89 | |
| 1004 | 8.5 | 11 03 29 | -58 29 58 | -58°3069 | 8.96 | - 6 | -16 | 12 | 13 | 86 | |
| 1005 | 8.7 | 11 03 26 | -58 27 37 | -58°3066 | 8.89 | -10 | -15 | 13 | 18 | 86 | 5 |
| 1006 | 10.7 | 11 03 22 | -58 28 55 | | | 347 | -194 | 19 | 10 | 0 | 6 |
| 1007 | 10.8 | 11 03 15 | -58 28 22 | | 11.70 | - 9 | 34 | 14 | 14 | 64 | |
| 1008 | 9.3 | 11 03 11 | -58 30 02 | -58°3057 | 9.67 | - 3 | - 7 | 14 | 9 | 90 | |
| 1009 | 10.6 | 11 03 11 | -58 29 49 | | 9.80 | -74 | -14 | 11 | 19 | 0 | 3 |
| 1010 | 8.2 | 11 03 10 | -58 30 49 | -58°3056 | 8.52 | 12 | - 2 | 10 | 13 | 89 | |
| 1011 | 10.1 | 11 03 08 | -58 28 23 | -58°3054 | 10.90 | 15 | -30 | 15 | 11 | 60 | |
| 1012 | 10.3 | 11 03 07 | -58 28 20 | | 11.27 | -15 | 43 | 13 | 10 | 32 | |
| 1013 | 10.9 | 11 03 04 | -58 30 25 | | | 58 | -64 | 20 | 17 | 0 | 3 |
| 1014 | 8.9 | 11 03 01 | -58 30 32 | -58°3049 | 9.30 | 20 | -13 | 17 | 12 | 79 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1015 | 10.8 | 11 03 00 | -58 30 38 | | | -56 | -11 | 26 | 13 | 4 | 3 |
| 1016 | 10.8 | 11 02 57 | -58 29 30 | | | -21 | -18 | 20 | 7 | 75 | |
| 1017 | 9.7 | 11 02 54 | -58 29 06 | $-58^{\circ}3042$ | 10.37 | 3 | - 8 | 8 | 6 | 90 | |
| 1018 | 8.0 | 11 02 48 | -58 28 47 | $-58^{\circ}3037$ | 8.20 | 22 | - 3 | 6 | 7 | 82 | |
| 1019 | 9.3 | 11 02 47 | -58 26 56 | $-58^{\circ}3036$ | 9.48 | 10 | 16 | 17 | 4 | 87 | 3 |
| 1020 | 9.3 | 11 02 43 | -58 26 51 | $-58^{\circ}3031$ | 7.92 | -20 | -106 | 20 | 15 | 0 | |
| 1021 | 9.7 | 11 02 43 | -58 30 47 | $-58^{\circ}3034$ | 10.53 | -63 | 20 | 14 | 9 | 0 | |
| 1022 | 10.7 | 11 02 36 | -58 30 28 | | 11.92 | -23 | 20 | 14 | 15 | 69 | |
| 1023 | 10.1 | 11 02 35 | -58 30 47 | $-58^{\circ}3025$ | 10.95 | 24 | 15 | 11 | 9 | 78 | |
| 1024 | 9.9 | 11 02 34 | -58 30 31 | $-58^{\circ}3022$ | 10.09 | 21 | -22 | 4 | 19 | 67 | |
| 1025 | 9.1 | 11 02 30 | -58 27 38 | $-58^{\circ}3017$ | 9.79 | - 3 | 3 | 8 | 10 | 91 | |
| 1026 | 8.2 | 11 02 29 | -58 29 08 | $-58^{\circ}3016$ | 7.64 | 11 | 26 | 16 | 10 | 80 | |
| 1027 | 10.8 | 11 02 21 | -58 26 56 | | | 0 | 12 | 18 | 18 | 90 | |
| 1028 | 10.1 | 11 02 20 | -58 30 19 | $-58^{\circ}3009$ | 10.92 | -10 | 5 | 12 | 4 | 90 | |
| 1029 | 9.7 | 11 02 17 | -58 27 21 | $-58^{\circ}3007$ | 10.31 | 0 | - 9 | 7 | 14 | 90 | |
| 1030 | 8.2 | 11 02 13 | -58 29 59 | $-58^{\circ}3005$ | 8.21 | -15 | - 3 | 17 | 4 | 87 | |
| 1031 | 8.5 | 11 02 06 | -58 27 30 | $-58^{\circ}3003$ | 7.95 | 39 | -24 | 10 | 4 | 20 | |
| 1032 | 10.7 | 11 01 54 | -58 26 59 | | 11.68 | -15 | - 8 | 15 | 14 | 86 | |
| 1033 | 10.8 | 11 01 52 | -58 29 37 | | | -15 | 64 | 10 | 15 | 2 | |
| 1034 | 8.2 | 11 01 47 | -58 29 43 | $-58^{\circ}2995$ | 8.10 | 32 | 19 | 16 | 25 | 60 | |
| 1035 | 10.8 | 11 01 46 | -58 31 01 | | | 0 | 25 | 11 | 9 | 82 | |
| 1036 | 8.7 | 11 01 38 | -58 31 04 | $-58^{\circ}2993$ | 9.15 | - 5 | - 7 | 7 | 8 | 90 | |
| 1037 | 10.6 | 11 01 29 | -58 30 56 | | | 28 | -19 | 13 | 17 | 57 | |
| 1038 | 10.8 | 11 01 27 | -58 28 36 | | | 33 | 48 | 15 | 11 | 10 | |
| 1039 | 10.8 | 11 01 27 | -58 27 26 | | | -124 | -107 | 6 | 1 | 0 | 6 |
| 1040 | 9.1 | 11 01 25 | -58 29 04 | $-58^{\circ}2987$ | | -24 | -37 | 12 | 10 | 35 | |
| 1041 | 9.1 | 11 01 23 | -58 30 57 | $-58^{\circ}2986$ | 9.22 | -221 | 35 | 12 | 7 | 0 | 6 |
| 1042 | 9.5 | 11 01 14 | -58 29 18 | $-58^{\circ}2983$ | | -21 | -43 | 6 | 11 | 24 | |
| 1043 | 10.7 | 11 01 11 | -58 29 03 | | | -13 | 31 | 9 | 7 | 66 | |
| 1044 | 10.8 | 11 01 01 | -58 29 11 | | | 27 | 64 | 15 | 20 | 2 | |
| 1045 | 10.7 | 11 00 58 | -58 28 42 | | | 50 | - 4 | 12 | 9 | 13 | |
| 1046 | 10.3 | 11 00 52 | -58 29 52 | $-58^{\circ}2973$ | | -149 | -24 | 10 | 14 | 0 | |
| 1047 | 9.9 | 11 00 49 | -58 27 29 | $-58^{\circ}2971$ | | - 5 | 34 | 13 | 7 | 67 | |
| 1048 | 9.9 | 11 00 48 | -58 29 56 | $-58^{\circ}2970$ | | 9 | 14 | 13 | 9 | 89 | |
| 1049 | 10.5 | 11 00 41 | -58 28 08 | | | -23 | 32 | 9 | 7 | 47 | |
| 1050 | 10.8 | 11 00 36 | -58 28 32 | | | 79 | -56 | 25 | 15 | 0 | |
| 1051 | 10.7 | 11 00 33 | -58 30 58 | | | -24 | 10 | 19 | 14 | 77 | |
| 1052 | 10.3 | 11 00 31 | -58 27 51 | $-58^{\circ}2959$ | | -31 | 36 | 10 | 8 | 20 | |
| 1053 | 9.7 | 11 00 24 | -58 28 13 | $-58^{\circ}2954$ | | - 6 | 19 | 12 | 11 | 86 | |
| 1054 | 8.7 | 11 00 19 | -58 29 27 | $-58^{\circ}2953$ | | -310 | -110 | 16 | 7 | 0 | 6 |
| 1055 | 10.8 | 11 00 18 | -58 26 52 | | | 55 | -62 | 7 | 21 | 0 | |
| 1056 | 9.1 | 11 00 05 | -58 31 18 | $-58^{\circ}2949$ | | - 2 | 9 | 10 | 24 | 91 | |
| 1098 | 10.7 | 11 07 07 | -58 23 10 | | | 28 | - 3 | 7 | 13 | 73 | |
| 1099 | 10.7 | 11 06 58 | -58 22 09 | | | -17 | 38 | 25 | 9 | 43 | |
| 1100 | 11.0 | 11 06 56 | -58 23 13 | | | 10 | 41 | 23 | 8 | 50 | 3 |
| 1101 | 10.8 | 11 06 55 | -58 25 06 | | | - 1 | 24 | 8 | 12 | 83 | |
| 1102 | 10.5 | 11 06 34 | -58 24 48 | $-58^{\circ}3192$ | | 64 | - 2 | 15 | 23 | 1 | |
| 1103 | 9.9 | 11 06 32 | -58 25 36 | $-58^{\circ}3191$ | | -62 | 8 | 14 | 11 | 1 | |
| 1104 | 10.7 | 11 06 27 | -58 21 20 | $-57^{\circ}4338$ | | 213 | -147 | 32 | 2 | 0 | 2,6 |
| 1105 | 10.5 | 11 06 26 | -58 21 26 | | | -12 | 43 | 16 | 21 | 36 | |
| 1106 | 9.1 | 11 06 24 | -58 24 32 | $-58^{\circ}3187$ | | 4 | - 6 | 15 | 17 | 90 | |
| 1107 | 10.1 | 11 06 15 | -58 24 35 | $-58^{\circ}3182$ | | 3 | 40 | 4 | 16 | 55 | |
| 1108 | 10.8 | 11 06 15 | -58 24 41 | | | 18 | 35 | 15 | 15 | 59 | |
| 1109 | 9.7 | 11 06 09 | -58 25 22 | $-58^{\circ}3180$ | | 29 | -24 | 11 | 17 | 45 | |
| 1110 | 9.7 | 11 06 07 | -58 23 54 | $-57^{\circ}4329$ | | 3 | -13 | 13 | 11 | 88 | |
| 1111 | 10.5 | 11 05 57 | -58 23 10 | | | -22 | 40 | 6 | 8 | 29 | |
| 1112 | 9.3 | 11 05 45 | -58 22 45 | $-57^{\circ}4319$ | | 4 | - 5 | 8 | 8 | 91 | |
| 1113 | 9.3 | 11 05 27 | -58 24 32 | $-58^{\circ}3157$ | 10.13 | - 6 | 4 | 14 | 13 | 91 | |
| 1114 | 10.1 | 11 05 26 | -58 22 11 | $-57^{\circ}4310$ | | 9 | 24 | 17 | 11 | 82 | |
| 1115 | 9.7 | 11 05 09 | -58 24 35 | $-58^{\circ}3151$ | 10.10 | -258 | 118 | 14 | 16 | 0 | 6 |
| 1116 | 9.5 | 11 05 08 | -58 26 04 | $-58^{\circ}3150$ | 9.85 | 13 | -27 | 12 | 14 | 69 | |
| 1117 | 10.6 | 11 05 00 | -58 24 51 | | | -22 | 4 | 8 | 9 | 81 | |
| 1118 | 9.3 | 11 04 51 | -58 22 28 | $-57^{\circ}4291$ | 9.88 | 13 | - 3 | 12 | 9 | 89 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1119 | 10.1 | 11 04 48 | -58 23 56 | -57°4289 | 10.90 | - 2 | - 2 | 13 | 11 | 91 | |
| 1120 | 8.5 | 11 04 43 | -58 26 10 | -58°3131 | 8.65 | -20 | 15 | 16 | 5 | 79 | |
| 1121 | 10.6 | 11 04 43 | -58 22 05 | | 11.46 | -17 | 2 | 12 | 13 | 86 | |
| 1122 | 10.6 | 11 04 42 | -58 22 37 | | | 21 | -36 | 5 | 4 | 34 | |
| 1123 | 9.9 | 11 04 40 | -58 22 52 | -57°4285 | | 0 | 19 | 5 | 11 | 87 | |
| 1124 | 10.7 | 11 04 38 | -58 25 09 | | 11.67 | -35 | 28 | 18 | 26 | 26 | 3 |
| 1125 | 10.7 | 11 04 35 | -58 21 33 | | | 15 | 12 | 7 | 12 | 87 | |
| 1126 | 9.7 | 11 04 23 | -58 22 33 | -57°4274 | 10.38 | -54 | 51 | 17 | 38 | 0 | 3 |
| 1127 | 7.8 | 11 04 21 | -58 24 18 | -58°3112 | 6.02 | -17 | 56 | 22 | 19 | 6 | |
| 1128 | 9.7 | 11 04 20 | -58 25 57 | -58°3111 | 10.72 | -37 | - 2 | 30 | 16 | 50 | 3 |
| 1129 | 9.3 | 11 04 18 | -58 24 33 | -58°3109 | 9.87 | -45 | - 6 | 10 | 3 | 24 | |
| 1130 | 8.9 | 11 04 16 | -58 25 28 | -58°3107 | 9.31 | -14 | 3 | 5 | 9 | 88 | 3 |
| 1131 | 10.6 | 11 04 12 | -58 22 07 | | | 15 | -11 | 11 | 11 | 85 | |
| 1132 | 10.8 | 11 04 12 | -58 25 12 | | | 13 | 70 | 2 | 6 | 1 | 3 |
| 1133 | 10.3 | 11 04 04 | -58 23 25 | -57°4261 | 11.12 | -11 | 32 | 12 | 16 | 66 | |
| 1134 | 8.7 | 11 04 03 | -58 25 36 | -58°3099 | 8.82 | 40 | -10 | 15 | 18 | 35 | |
| 1135 | 9.7 | 11 04 02 | -58 25 31 | | 9.89 | 10 | 0 | 14 | 13 | 90 | |
| 1136 | 9.5 | 11 04 01 | -58 24 01 | -57°4258 | 9.93 | 2 | - 7 | 12 | 21 | 90 | |
| 1137 | 8.5 | 11 04 00 | -58 22 05 | -57°4257 | 8.59 | - 8 | -10 | 10 | 9 | 89 | |
| 1138 | 10.3 | 11 03 59 | -58 23 37 | -57°4256 | 11.26 | 2 | 33 | 7 | 16 | 71 | |
| 1139 | 9.3 | 11 03 58 | -58 24 40 | -58°3094 | 9.52 | 10 | 18 | 12 | 11 | 86 | |
| 1140 | 8.2 | 11 03 56 | -58 25 03 | -58°3092 | 7.48 | -25 | 2 | 15 | 11 | 78 | |
| 1141 | 9.1 | 11 03 49 | -58 25 19 | -58°3087 | 9.27 | -29 | 10 | 16 | 16 | 67 | |
| 1142 | 8.7 | 11 03 47 | -58 24 17 | -58°3085 | 9.15 | 3 | - 8 | 5 | 9 | 90 | |
| 1143 | 8.5 | 11 03 46 | -58 23 32 | -57°4253 | 8.50 | -19 | -70 | 8 | 17 | 0 | |
| 1144 | 9.7 | 11 03 45 | -58 22 47 | -57°4251 | 10.36 | -25 | 24 | 14 | 14 | 59 | |
| 1145 | 10.8 | 11 03 43 | -58 26 05 | | | -35 | 41 | 2 | 22 | 8 | |
| 1146 | 9.3 | 11 03 42 | -58 25 58 | -58°3080 | 9.57 | - 8 | 0 | 11 | 14 | 90 | |
| 1147 | 8.9 | 11 03 38 | -58 24 26 | -58°3077 | 8.15 | - 2 | 29 | 18 | 8 | 77 | |
| 1148 | 9.9 | 11 03 32 | -58 23 20 | -57°4238 | 10.51 | 39 | -25 | 8 | 13 | 19 | |
| 1149 | 9.9 | 11 03 28 | -58 24 23 | -58°3068 | 10.66 | 14 | - 9 | 11 | 7 | 86 | |
| 1150 | 10.9 | 11 03 27 | -58 22 57 | | | - 8 | - 8 | 16 | 8 | 89 | |
| 1151 | 10.6 | 11 03 15 | -58 22 58 | | 11.41 | -16 | 31 | 1 | 22 | 62 | |
| 1152 | 10.1 | 11 03 13 | -58 22 21 | -57°4228 | 10.81 | 7 | 5 | 7 | 11 | 91 | |
| 1153 | 9.1 | 11 03 12 | -58 24 24 | -58°3058 | 9.59 | -17 | 0 | 7 | 10 | 86 | |
| 1154 | 10.5 | 11 03 10 | -58 26 07 | | 11.32 | -35 | - 6 | 10 | 19 | 55 | |
| 1155 | 9.7 | 11 03 09 | -58 22 31 | -57°4223 | 10.59 | - 5 | 2 | 8 | 15 | 91 | |
| 1156 | 10.8 | 11 02 59 | -58 22 18 | | 11.44 | 4 | 23 | 15 | 3 | 84 | |
| 1157 | 9.1 | 11 02 56 | -58 24 56 | -58°3044 | 9.55 | 27 | 10 | 6 | 18 | 76 | |
| 1158 | 8.7 | 11 02 55 | -58 26 01 | -58°3043 | 9.33 | 3 | -24 | 9 | 8 | 79 | |
| 1159 | 10.8 | 11 02 52 | -58 24 27 | | 11.10 | -151 | 107 | 21 | 16 | 0 | |
| 1160 | 8.2 | 11 02 49 | -58 23 45 | -57°4208 | 8.34 | -22 | -53 | 17 | 14 | 7 | |
| 1161 | 9.9 | 11 02 44 | -58 21 49 | -57°4205 | 10.74 | 52 | -48 | 10 | 4 | 0 | |
| 1162 | 10.7 | 11 02 44 | -58 25 31 | | | -22 | - 3 | 3 | 21 | 82 | |
| 1163 | 9.9 | 11 02 41 | -58 23 18 | -57°4203 | 10.67 | - 4 | - 2 | 9 | 10 | 91 | |
| 1164 | 10.8 | 11 02 40 | -58 24 24 | | | 18 | 18 | 11 | 17 | 82 | |
| 1165 | 8.5 | 11 02 38 | -58 25 57 | -58°3028 | 8.30 | 43 | 10 | 14 | 14 | 33 | |
| 1166 | 8.7 | 11 02 37 | -58 25 33 | -58°3027 | 8.66 | - 4 | - 8 | 25 | 12 | 90 | |
| 1167 | 10.3 | 11 02 33 | -58 23 30 | -57°4196 | 11.22 | 24 | 9 | 16 | 7 | 80 | |
| 1168 | 8.7 | 11 02 32 | -58 24 55 | -58°3019 | 9.17 | 11 | - 2 | 19 | 7 | 90 | |
| 1169 | 10.8 | 11 02 28 | -58 23 18 | | | - 8 | 34 | 18 | 18 | 65 | |
| 1170 | 8.5 | 11 02 27 | -58 25 27 | -58°3014 | 7.78 | 4 | 14 | 10 | 15 | 89 | |
| 1171 | 10.6 | 11 02 27 | -58 24 54 | | 11.44 | - 3 | 18 | 7 | 6 | 87 | |
| 1172 | 10.7 | 11 02 26 | -58 26 17 | | 10.79 | -37 | 4 | 14 | 14 | 48 | |
| 1173 | 10.5 | 11 02 16 | -58 25 09 | | 11.48 | 8 | 35 | 5 | 11 | 66 | |
| 1174 | 10.3 | 11 02 14 | -58 24 01 | -57°4188 | 11.36 | 52 | -41 | 10 | 18 | 0 | |
| 1175 | 10.8 | 11 01 37 | -58 24 53 | | | 8 | 0 | 10 | 9 | 91 | |
| 1176 | 10.3 | 11 01 30 | -58 24 08 | -58°2991 | | 49 | 25 | 25 | 13 | 11 | |
| 1177 | 10.8 | 11 01 29 | -58 25 02 | | | - 3 | - 4 | 15 | 11 | 91 | |
| 1178 | 10.8 | 11 01 26 | -58 24 25 | | | 35 | -21 | 19 | 17 | 35 | |
| 1179 | 10.7 | 11 00 56 | -58 26 02 | | | - 4 | -36 | 17 | 9 | 56 | |
| 1180 | 11.0 | 11 00 49 | -58 22 19 | | | 26 | - 3 | 15 | 15 | 77 | 3 |
| 1181 | 8.5 | 11 00 45 | -58 25 57 | -58°2968 | | 4 | - 2 | 14 | 6 | 91 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1182 | 10.8 | 11 00 41 | -58 24 29 | | | 89 | -16 | 12 | 13 | 0 | |
| 1183 | 10.7 | 11 00 29 | -58 24 51 | $-58^{\circ}2957$ | | 10 | -32 | 17 | 19 | 61 | |
| 1184 | 9.9 | 11 00 08 | -58 26 13 | $-58^{\circ}2950$ | | -29 | 12 | 12 | 18 | 65 | |
| 1185 | 10.6 | 10 59 56 | -58 25 04 | $-58^{\circ}2946$ | | 115 | -52 | 11 | 10 | 0 | |
| 1186 | 10.7 | 10 59 38 | -58 22 54 | | | -55 | - 9 | 12 | 15 | 5 | |
| 1224 | 10.8 | 11 06 58 | -58 21 01 | | | -22 | 15 | 22 | 10 | 76 | |
| 1225 | 9.9 | 11 06 55 | -58 18 17 | $-57^{\circ}4344$ | | - 8 | - 3 | 12 | 13 | 90 | |
| 1226 | 10.8 | 11 06 13 | -58 18 20 | | | - 6 | 54 | 15 | 3 | 13 | |
| 1227 | 10.8 | 11 06 12 | -58 18 46 | | | -64 | - 9 | 28 | 12 | 1 | |
| 1228 | 10.8 | 11 05 30 | -58 18 32 | | | -11 | -23 | 26 | 13 | 79 | |
| 1229 | 10.8 | 11 06 06 | -58 18 07 | | | 91 | -19 | 24 | 23 | 0 | 2 |
| 1230 | 10.7 | 11 05 19 | -58 16 43 | | | 10 | -16 | 14 | 15 | 85 | |
| 1231 | 9.9 | 11 05 02 | -58 21 16 | $-57^{\circ}4297$ | 10.94 | 2 | 27 | 11 | 10 | 80 | |
| 1232 | 9.9 | 11 04 48 | -58 21 10 | $-57^{\circ}4288$ | 10.76 | -13 | 22 | 6 | 9 | 80 | |
| 1233 | 9.3 | 11 04 36 | -58 18 49 | $-57^{\circ}4279$ | 8.30 | -28 | -92 | 19 | 9 | 0 | |
| 1234 | 10.8 | 11 04 35 | -58 19 43 | | | -51 | -31 | 10 | 9 | 4 | |
| 1235 | 9.9 | 11 04 24 | -58 20 56 | $-57^{\circ}4275$ | 10.67 | -39 | 6 | 9 | 11 | 41 | |
| 1236 | 10.5 | 11 04 17 | -58 18 20 | | 11.50 | -37 | 13 | 8 | 13 | 42 | |
| 1237 | 10.8 | 11 04 17 | -58 19 52 | | | 4 | 1 | 17 | 8 | 91 | |
| 1238 | 10.8 | 11 04 10 | -58 17 41 | | 11.13 | -69 | -20 | 16 | 6 | 0 | |
| 1239 | 10.7 | 11 04 08 | -58 17 20 | | 11.66 | -156 | 61 | 6 | 22 | 0 | |
| 1240 | 10.8 | 11 03 51 | -58 18 05 | | | 27 | -30 | 25 | 17 | 37 | |
| 1241 | 10.8 | 11 03 50 | -58 17 57 | | | -47 | -42 | 18 | 22 | 2 | 3 |
| 1242 | 10.3 | 11 03 46 | -58 19 24 | $-57^{\circ}4254$ | 11.10 | - 6 | - 8 | 5 | 9 | 90 | |
| 1243 | 10.3 | 11 03 41 | -58 19 27 | $-57^{\circ}4245$ | 11.34 | 67 | -23 | 9 | 19 | 0 | |
| 1244 | 9.5 | 11 03 41 | -58 19 01 | $-57^{\circ}4246$ | 10.30 | -16 | -15 | 16 | 10 | 83 | |
| 1245 | 10.8 | 11 03 39 | -58 20 36 | | | -22 | - 3 | 29 | 15 | 82 | |
| 1246 | 9.3 | 11 03 33 | -58 19 39 | $-57^{\circ}4239$ | 9.93 | 21 | - 1 | 9 | 11 | 84 | |
| 1247 | 10.7 | 11 03 29 | -58 21 23 | | | 44 | -15 | 17 | 10 | 19 | |
| 1248 | 9.9 | 11 03 28 | -58 20 49 | $-57^{\circ}4237$ | 10.52 | -14 | 13 | 7 | 10 | 85 | |
| 1250 | 9.9 | 11 03 24 | -58 20 51 | | 9.52 | -46 | -27 | 3 | 6 | 10 | 2 |
| 1251 | 9.9 | 11 03 18 | -58 19 44 | $-57^{\circ}4233$ | 10.75 | -13 | 2 | 4 | 14 | 89 | |
| 1252 | 9.7 | 11 03 07 | -58 19 36 | $-57^{\circ}4221$ | 10.87 | 17 | - 9 | 6 | 3 | 84 | |
| 1253 | 10.3 | 11 03 06 | -58 20 01 | $-57^{\circ}4220$ | 11.38 | 1 | -39 | 6 | 20 | 47 | |
| 1254 | 9.5 | 11 02 56 | -58 19 37 | $-57^{\circ}4210$ | 10.21 | 11 | - 3 | 18 | 7 | 89 | |
| 1255 | 8.2 | 11 02 47 | -58 16 55 | $-57^{\circ}4206$ | 8.21 | 58 | -48 | 27 | 20 | 0 | |
| 1256 | 10.3 | 11 02 40 | -58 20 25 | | 10.96 | 17 | 1 | 23 | 18 | 87 | |
| 1257 | 9.9 | 11 02 39 | -58 20 13 | $-57^{\circ}4201$ | 10.51 | 22 | - 9 | 11 | 18 | 79 | |
| 1258 | 10.8 | 11 02 29 | -58 19 48 | | | 41 | 40 | 26 | 28 | 10 | |
| 1259 | 10.6 | 11 02 26 | -58 16 50 | | 11.72 | -15 | -27 | 9 | 9 | 70 | |
| 1260 | 9.5 | 11 02 11 | -58 20 28 | $-57^{\circ}4186$ | 10.36 | - 5 | 2 | 20 | 6 | 91 | |
| 1261 | 9.5 | 11 02 11 | -58 20 16 | $-57^{\circ}4183$ | 10.29 | 15 | 3 | 14 | 10 | 88 | |
| 1262 | 10.3 | 11 01 56 | -58 19 49 | $-57^{\circ}4176$ | 11.03 | - 1 | 11 | 7 | 13 | 90 | |
| 1263 | 10.6 | 11 01 48 | -58 19 45 | | 11.67 | 22 | -17 | 9 | 12 | 72 | |
| 1264 | 9.5 | 11 01 42 | -58 19 07 | $-57^{\circ}4169$ | 10.23 | 67 | -39 | 7 | 4 | 0 | |
| 1265 | 9.5 | 11 01 42 | -58 18 25 | $-57^{\circ}4168$ | 10.04 | 30 | -33 | 14 | 2 | 24 | |
| 1266 | 10.7 | 11 01 41 | -58 21 09 | | | -172 | 62 | 12 | 16 | 0 | |
| 1267 | 10.8 | 11 01 41 | -58 20 26 | | | -16 | 43 | 10 | 13 | 30 | |
| 1268 | 10.8 | 11 01 40 | -58 18 59 | | | 14 | -33 | 12 | 18 | 54 | |
| 1269 | 10.3 | 11 01 38 | -58 20 19 | $-57^{\circ}4166$ | 11.39 | 0 | 5 | 13 | 12 | 91 | |
| 1270 | 10.7 | 11 01 36 | -58 19 56 | | | 62 | -17 | 15 | 6 | 1 | |
| 1271 | 8.7 | 11 01 27 | -58 17 23 | $-57^{\circ}4156$ | 9.15 | 1 | 5 | 11 | 11 | 91 | |
| 1272 | 10.8 | 11 01 09 | -58 19 14 | | | 20 | -31 | 16 | 9 | 49 | |
| 1273 | 9.3 | 11 01 08 | -58 19 36 | $-57^{\circ}4142$ | | -19 | 12 | 14 | 15 | 82 | |
| 1274 | 9.9 | 11 00 58 | -58 18 55 | $-57^{\circ}4138$ | | 9 | -36 | 14 | 3 | 51 | |
| 1275 | 10.7 | 11 00 52 | -58 20 07 | | | -21 | 23 | 9 | 21 | 68 | |
| 1276 | 10.8 | 11 00 51 | -58 20 17 | | | -55 | 30 | 24 | 24 | 1 | |
| 1277 | 10.1 | 11 00 30 | -58 17 59 | $-57^{\circ}4126$ | | -25 | 2 | 14 | 4 | 78 | |
| 1278 | 10.7 | 11 00 24 | -58 17 40 | | | 81 | 16 | 9 | 23 | 0 | |
| 1279 | 9.5 | 11 00 23 | -58 18 21 | $-57^{\circ}4122$ | | - 9 | -11 | 10 | 3 | 88 | |
| 1280 | 9.9 | 11 00 08 | -58 18 33 | $-57^{\circ}4118$ | | -21 | 15 | 13 | 11 | 77 | |
| 1281 | 10.5 | 11 00 00 | -58 18 36 | | | - 5 | 20 | 20 | 11 | 86 | |
| 1282 | 9.9 | 10 59 44 | -58 19 28 | $-57^{\circ}4111$ | | -30 | -24 | 14 | 5 | 50 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1283 | 10.8 | 10 59 36 | -58 18 56 | | | 45 | -76 | 19 | 23 | 0 | |
| 1284 | 10.7 | 10 59 35 | -58 18 39 | | | 26 | -39 | 18 | 6 | 19 | |
| 1327 | 9.7 | 11 07 02 | -58 15 59 | $-57^{o}4346$ | | 16 | - 1 | 11 | 14 | 87 | |
| 1328 | 10.3 | 11 07 00 | -58 11 16 | $-57^{o}4345$ | | - 9 | - 6 | 18 | 3 | 89 | |
| 1329 | 10.6 | 11 06 42 | -58 13 20 | | | 2 | 3 | 13 | 12 | 91 | |
| 1330 | 9.1 | 11 06 28 | -58 15 44 | $-57^{o}4337$ | | -28 | 17 | 17 | 12 | 63 | |
| 1331 | 9.7 | 11 06 24 | -58 15 28 | $-57^{o}4336$ | | - 6 | 6 | 16 | 16 | 90 | |
| 1332 | 8.5 | 11 05 55 | -58 13 46 | $-57^{o}4322$ | | - 9 | 34 | 6 | 19 | 64 | |
| 1333 | 9.1 | 11 05 39 | -58 12 51 | $-57^{o}4315$ | | 7 | - 4 | 10 | 21 | 90 | |
| 1334 | 8.7 | 11 05 33 | -58 14 08 | $-57^{o}4312$ | | -74 | 41 | 8 | 21 | 0 | |
| 1335 | 8.7 | 11 05 22 | -58 12 10 | $-57^{o}4306$ | | - 2 | 9 | 7 | 8 | 91 | |
| 1336 | 10.3 | 11 05 08 | -58 12 15 | $-57^{o}4300$ | | -18 | - 4 | 14 | 3 | 85 | |
| 1337 | 10.3 | 11 05 04 | -58 12 48 | $-57^{o}4299$ | | -20 | 46 | 6 | 18 | 18 | |
| 1338 | 10.7 | 11 05 04 | -58 12 39 | | | - 5 | 30 | 27 | 5 | 75 | 3 |
| 1339 | 8.9 | 11 05 01 | -58 15 24 | $-57^{o}4296$ | 9.64 | -23 | - 9 | 9 | 6 | 79 | |
| 1340 | 10.7 | 11 05 00 | -58 14 18 | | | -26 | 39 | 9 | 15 | 24 | |
| 1341 | 10.6 | 11 04 59 | -58 12 04 | | | -271 | 153 | 12 | 21 | 0 | 6 |
| 1342 | 8.7 | 11 04 54 | -58 11 34 | $-57^{o}4293$ | | 10 | 59 | 7 | 18 | 7 | |
| 1343 | 9.5 | 11 04 49 | -58 11 52 | $-57^{o}4290$ | | 8 | 9 | 14 | 22 | 90 | |
| 1344 | 10.7 | 11 04 47 | -58 14 28 | | | -19 | -17 | 19 | 16 | 78 | |
| 1345 | 10.3 | 11 04 39 | -58 15 52 | $-57^{o}4282$ | 11.30 | -35 | - 4 | 12 | 18 | 56 | |
| 1346 | 10.8 | 11 04 21 | -58 14 00 | | | -41 | 25 | 6 | 20 | 16 | |
| 1347 | 8.5 | 11 04 18 | -58 15 23 | $-57^{o}4272$ | 9.19 | - 2 | -15 | 11 | 8 | 88 | |
| 1348 | 10.3 | 11 04 16 | -58 15 37 | $-57^{o}4271$ | 11.25 | - 6 | 5 | 18 | 29 | 91 | 3 |
| 1349 | 9.5 | 11 04 15 | -58 14 09 | $-57^{o}4270$ | | - 6 | 0 | 11 | 12 | 91 | |
| 1350 | 10.6 | 11 04 13 | -58 14 08 | | | 13 | -12 | 6 | 14 | 86 | |
| 1351 | 10.7 | 11 04 11 | -58 12 13 | | | - 7 | 30 | 18 | 13 | 73 | |
| 1352 | 10.5 | 11 04 10 | -58 16 27 | | 10.59 | 33 | -20 | 18 | 12 | 42 | |
| 1353 | 10.8 | 11 03 59 | -58 12 49 | | | -44 | 10 | 5 | 14 | 23 | |
| 1354 | 10.8 | 11 03 54 | -58 15 48 | | | -32 | 38 | 8 | 8 | 15 | |
| 1355 | 9.9 | 11 03 43 | -58 13 25 | $-57^{o}4249$ | | 27 | -25 | 9 | 11 | 48 | |
| 1356 | 8.9 | 11 03 41 | -58 16 16 | $-57^{o}4247$ | 9.38 | - 8 | - 4 | 15 | 11 | 90 | |
| 1357 | 10.8 | 11 03 38 | -58 11 43 | | | -17 | 45 | 28 | 19 | 24 | 3 |
| 1358 | 9.5 | 11 03 37 | -58 13 17 | $-57^{o}4243$ | | -11 | 23 | 15 | 7 | 80 | |
| 1359 | 10.1 | 11 03 35 | -58 13 59 | $-57^{o}4242$ | | -106 | 70 | 13 | 9 | 0 | |
| 1360 | 10.8 | 11 03 27 | -58 13 05 | | | -10 | - 1 | 10 | 7 | 90 | |
| 1361 | 9.1 | 11 03 19 | -58 16 31 | $-57^{o}4232$ | 9.70 | 0 | - 5 | 15 | 18 | 91 | |
| 1362 | 10.6 | 11 03 02 | -58 13 57 | | | -18 | - 1 | 12 | 7 | 86 | |
| 1363 | 10.8 | 11 02 58 | -58 13 44 | | | 0 | - 6 | 23 | 25 | 91 | |
| 1364 | 9.9 | 11 02 57 | -58 12 51 | $-57^{o}4211$ | | 31 | 4 | 7 | 9 | 69 | |
| 1365 | 10.8 | 11 02 54 | -58 12 18 | | | 59 | -20 | 25 | 18 | 1 | |
| 1366 | 10.3 | 11 02 39 | -58 14 05 | $-57^{o}4202$ | | -108 | 4 | 7 | 22 | 0 | |
| 1367 | 9.5 | 11 02 37 | -58 12 20 | $-57^{o}4199$ | | - 9 | 6 | 24 | 10 | 90 | |
| 1369 | 10.3 | 11 02 29 | -58 12 05 | $-57^{o}4193$ | | -12 | -11 | 11 | 2 | 87 | |
| 1370 | 9.5 | 11 02 29 | -58 13 44 | $-57^{o}4192$ | | - 4 | 7 | 13 | 3 | 91 | |
| 1371 | 9.9 | 11 02 27 | -58 15 35 | $-57^{o}4191$ | 10.19 | 13 | -30 | 21 | 9 | 62 | |
| 1372 | 9.7 | 11 02 16 | -58 13 25 | $-57^{o}4189$ | | 3 | 94 | 6 | 15 | 0 | |
| 1373 | 10.7 | 11 02 08 | -58 12 57 | | | 46 | -46 | 5 | 13 | 1 | |
| 1374 | 8.7 | 11 02 07 | -58 11 39 | $-57^{o}4181$ | | 26 | -31 | 24 | 22 | 37 | |
| 1375 | 10.8 | 11 01 59 | -58 12 27 | | | 23 | -84 | 9 | 8 | 0 | 3 |
| 1376 | 10.8 | 11 01 52 | -58 13 24 | | | - 7 | -33 | 24 | 1 | 63 | 2 |
| 1377 | 9.7 | 11 01 48 | -58 12 42 | $-57^{o}4173$ | | 0 | 13 | 11 | 10 | 90 | |
| 1378 | 9.9 | 11 01 41 | -58 15 53 | $-57^{o}4167$ | 11.36 | - 5 | 11 | 11 | 9 | 90 | |
| 1379 | 10.5 | 11 01 34 | -58 16 22 | $-57^{o}4161$ | | 13 | -14 | 25 | 15 | 84 | |
| 1380 | 9.5 | 11 01 29 | -58 12 56 | $-57^{o}4157$ | | - 8 | -33 | 18 | 12 | 63 | |
| 1381 | 9.5 | 11 01 20 | -58 13 39 | $-57^{o}4151$ | | - 9 | -13 | 15 | 9 | 87 | |
| 1382 | 8.7 | 11 01 15 | -58 12 22 | $-57^{o}4145$ | | 0 | 8 | 17 | 9 | 91 | |
| 1383 | 10.5 | 11 01 11 | -58 13 08 | $-57^{o}4144$ | | 4 | 10 | 10 | 17 | 90 | |
| 1384 | 10.8 | 11 00 54 | -58 11 55 | | | -41 | - 2 | 26 | 11 | 37 | 3 |
| 1385 | 10.3 | 11 00 52 | -58 13 22 | $-57^{o}4136$ | | -16 | 1 | 13 | 16 | 87 | |
| 1386 | 10.8 | 11 00 45 | -58 11 42 | | | -29 | - 9 | 11 | 13 | 69 | |
| 1387 | 8.9 | 11 00 44 | -58 14 20 | $-57^{o}4133$ | | - 4 | 2 | 21 | 10 | 91 | |
| 1388 | 10.3 | 11 00 33 | -58 13 00 | $-57^{o}4131$ | | -14 | -10 | 16 | 13 | 86 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1389 | 10.5 | 11 00 26 | -58 15 40 | $-57^{o}4124$ | | -105 | -17 | 10 | 16 | 0 | |
| 1429 | 9.5 | 11 06 47 | -58 09 11 | $-57^{o}4341$ | | -51 | -32 | 6 | 5 | 3 | |
| 1430 | 10.6 | 11 06 27 | -58 08 59 | | | 56 | -15 | 12 | 20 | 3 | |
| 1431 | 10.8 | 11 06 24 | -58 08 58 | | | 19 | -17 | 9 | 10 | 76 | |
| 1432 | 8.2 | 11 06 21 | -58 09 38 | $-57^{o}4335$ | | 56 | 7 | 20 | 19 | 6 | |
| 1433 | 10.5 | 11 06 20 | -58 08 12 | | | -377 | -617 | 24 | 21 | 0 | 6 |
| 1434 | 9.5 | 11 06 14 | -58 09 24 | $-57^{o}4331$ | | -45 | -20 | 19 | 16 | 17 | |
| 1435 | 10.8 | 11 06 08 | -58 08 16 | | | -40 | -12 | 12 | 12 | 36 | |
| 1436 | 9.7 | 11 06 02 | -58 08 56 | $-57^{o}4326$ | | 42 | -30 | 3 | 11 | 8 | |
| 1437 | 10.8 | 11 06 01 | -58 09 46 | | | -199 | 4 | 28 | 17 | 0 | 3,6 |
| 1438 | 10.3 | 11 05 51 | -58 10 00 | $-57^{o}4321$ | | 1 | - 8 | 21 | 15 | 90 | |
| 1439 | 10.8 | 11 05 48 | -58 07 46 | | | 25 | 1 | 14 | 16 | 79 | |
| 1440 | 9.7 | 11 05 40 | -58 10 40 | $-57^{o}4316$ | | -13 | 13 | 5 | 13 | 86 | |
| 1441 | 10.3 | 11 05 34 | -58 07 08 | $-57^{o}4313$ | | 7 | -37 | 12 | 7 | 50 | |
| 1442 | 9.9 | 11 05 31 | -58 07 38 | $-57^{o}4311$ | | -15 | -20 | 19 | 5 | 79 | |
| 1443 | 10.8 | 11 05 17 | -58 10 17 | | | -50 | -64 | 9 | 15 | 0 | |
| 1444 | 10.7 | 11 05 04 | -58 07 20 | | | 40 | -32 | 2 | 19 | 9 | 2 |
| 1445 | 10.8 | 11 05 03 | -58 11 27 | | | 29 | -15 | 7 | 4 | 61 | |
| 1446 | 8.7 | 11 05 00 | -58 07 11 | $-57^{o}4295$ | | 6 | -31 | 13 | 4 | 66 | |
| 1447 | 10.8 | 11 04 55 | -58 11 04 | | | -20 | 6 | 16 | 13 | 83 | |
| 1448 | 10.8 | 11 04 43 | -58 10 29 | | | - 5 | -11 | 24 | 16 | 89 | |
| 1449 | 9.9 | 11 04 32 | -58 10 48 | $-57^{o}4278$ | | -22 | - 7 | 23 | 5 | 81 | |
| 1450 | 10.8 | 11 04 29 | -58 09 32 | | | 32 | -26 | 26 | 16 | 34 | |
| 1451 | 10.3 | 11 04 22 | -58 11 20 | $-57^{o}4273$ | | -13 | - 5 | 6 | 13 | 88 | |
| 1452 | 10.8 | 11 04 17 | -58 08 58 | | | 19 | 18 | 6 | 8 | 81 | |
| 1453 | 10.1 | 11 04 14 | -58 10 34 | $-57^{o}4268$ | | - 2 | 21 | 15 | 10 | 86 | |
| 1454 | 9.7 | 11 04 13 | -58 11 28 | $-57^{o}4266$ | | 7 | 0 | 19 | 18 | 91 | |
| 1455 | 9.7 | 11 04 12 | -58 09 37 | $-57^{o}4267$ | | 0 | -15 | 19 | 13 | 88 | |
| 1456 | 9.1 | 11 04 09 | -58 09 17 | $-57^{o}4264$ | | -18 | 18 | 16 | 3 | 79 | |
| 1457 | 10.7 | 11 04 04 | -58 08 08 | | | -18 | 26 | 4 | 12 | 69 | |
| 1458 | 10.8 | 11 04 04 | -58 07 58 | | | 5 | -25 | 24 | 9 | 77 | 3 |
| 1459 | 10.7 | 11 04 02 | -58 09 09 | | | -11 | 9 | 3 | 12 | 88 | |
| 1460 | 10.7 | 11 03 52 | -58 10 20 | | | -25 | - 7 | 12 | 21 | 77 | |
| 1461 | 10.8 | 11 03 48 | -58 09 39 | | | 102 | -135 | 26 | 6 | 0 | |
| 1462 | 10.5 | 11 03 24 | -58 11 10 | $-57^{o}4234$ | | 13 | 3 | 16 | 24 | 89 | |
| 1463 | 10.8 | 11 03 23 | -58 09 18 | | | 55 | -73 | 6 | 17 | 0 | |
| 1464 | 9.3 | 11 03 15 | -58 08 46 | $-57^{o}4230$ | | 1 | 13 | 4 | 25 | 90 | |
| 1465 | 10.3 | 11 03 09 | -58 08 28 | $-57^{o}4222$ | | 33 | -26 | 14 | 9 | 31 | |
| 1466 | 9.9 | 11 03 05 | -58 07 55 | $-57^{o}4218$ | | - 8 | 0 | 18 | 7 | 90 | |
| 1467 | 8.5 | 11 03 04 | -58 08 49 | $-57^{o}4217$ | | 15 | - 3 | 24 | 11 | 88 | |
| 1468 | 10.7 | 11 02 21 | -58 06 41 | | | -68 | -15 | 16 | 9 | 0 | |
| 1470 | 10.8 | 11 02 06 | -58 09 43 | | | 43 | -44 | 20 | 15 | 1 | |
| 1471 | 10.8 | 11 02 01 | -58 09 00 | | | 13 | 36 | 9 | 8 | 61 | |
| 1472 | 9.5 | 11 01 59 | -58 10 55 | $-57^{o}4177$ | | - 2 | - 4 | 12 | 16 | 91 | |
| 1473 | 9.1 | 11 01 56 | -58 10 28 | $-57^{o}4175$ | | - 8 | - 7 | 16 | 19 | 90 | |
| 1474 | 10.8 | 11 01 49 | -58 09 25 | | | -11 | - 4 | 20 | 9 | 89 | |
| 1475 | 10.1 | 11 01 47 | -58 08 54 | $-57^{o}4171$ | | 10 | 17 | 9 | 12 | 87 | |
| 1476 | 8.2 | 11 01 47 | -58 07 31 | $-57^{o}4170$ | | 67 | - 3 | 16 | 12 | 1 | |
| 1477 | 10.1 | 11 01 30 | -58 08 54 | $-57^{o}4158$ | | 67 | 24 | 9 | 6 | 0 | |
| 1478 | 9.7 | 11 01 28 | -58 09 20 | $-57^{o}4155$ | | - 6 | 39 | 7 | 11 | 54 | |
| 1479 | 9.5 | 11 01 14 | -58 10 06 | $-57^{o}4147$ | | - 4 | - 1 | 12 | 16 | 91 | |
| 1480 | 10.8 | 11 01 12 | -58 10 59 | | | 40 | -13 | 11 | 14 | 32 | |
| 1481 | 10.3 | 11 01 10 | -58 09 12 | $-57^{o}4143$ | | -119 | 77 | 13 | 10 | 0 | |
| 1482 | 8.7 | 11 01 05 | -58 07 15 | $-57^{o}4141$ | | 2 | 21 | 12 | 13 | 86 | |
| 1483 | 10.1 | 11 01 04 | -58 07 24 | | | -130 | 11 | 17 | 18 | 0 | |
| 1485 | 10.7 | 11 00 36 | -58 10 13 | | | 5 | 7 | 12 | 23 | 91 | |
| 1486 | 8.2 | 11 00 31 | -58 08 42 | $-57^{o}4127$ | | 14 | 11 | 6 | 20 | 88 | |
| 1487 | 10.8 | 11 00 23 | -58 11 00 | | | 47 | -40 | 17 | 19 | 1 | |
| 1488 | 10.8 | 10 59 37 | -58 08 39 | | | 4 | -20 | 14 | 13 | 84 | |
| 1489 | 10.8 | 10 59 36 | -58 08 59 | | | 25 | -22 | 17 | 15 | 59 | |
| 1490 | 10.8 | 10 59 36 | -58 07 14 | | | 32 | 21 | 17 | 8 | 57 | |
| 1518 | 10.6 | 11 07 04 | -58 02 56 | $-57^{o}4347$ | | -21 | -30 | 11 | 20 | 56 | |
| 1519 | 10.8 | 11 06 55 | -58 03 54 | | | 63 | 1 | 19 | 20 | 1 | 3 |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1520 | 10.7 | 11 06 26 | -58 04 40 | | | -25 | 20 | 25 | 9 | 65 | |
| 1521 | 10.6 | 11 06 20 | -58 04 07 | | | - 1 | 12 | 9 | 18 | 90 | |
| 1522 | 10.1 | 11 06 16 | -58 02 02 | $-57^o4332$ | | 77 | -20 | 24 | 19 | 0 | |
| 1523 | 10.3 | 11 06 02 | -58 03 42 | $-57^o4327$ | | 16 | -29 | 23 | 13 | 61 | |
| 1524 | 10.6 | 11 06 00 | -58 01 55 | | | 12 | - 7 | 6 | 7 | 88 | 3 |
| 1525 | 9.5 | 11 05 40 | -58 05 44 | $-57^o4317$ | | -68 | -42 | 3 | 9 | 0 | |
| 1526 | 10.8 | 11 05 34 | -58 06 24 | | | 50 | -74 | 3 | 24 | 0 | |
| 1527 | 10.8 | 11 05 12 | -58 05 25 | | | -34 | -32 | 16 | 26 | 26 | |
| 1528 | 10.7 | 11 04 59 | -58 06 21 | | | 10 | -25 | 8 | 10 | 75 | |
| 1529 | 10.8 | 11 04 59 | -58 05 56 | | | -46 | 15 | 26 | 18 | 15 | |
| 1530 | 10.7 | 11 04 49 | -58 04 24 | | | -77 | 10 | 14 | 6 | 0 | |
| 1531 | 10.8 | 11 04 42 | -58 02 21 | | | -21 | 26 | 18 | 11 | 64 | 3 |
| 1532 | 9.7 | 11 04 41 | -58 03 16 | $-57^o4284$ | | 2 | - 1 | 3 | 12 | 91 | |
| 1533 | 10.8 | 11 04 38 | -58 04 11 | | | -28 | 20 | 13 | 7 | 58 | |
| 1534 | 10.8 | 11 04 33 | -58 04 10 | | | -37 | -17 | 21 | 13 | 41 | |
| 1535 | 10.8 | 11 04 26 | -58 04 11 | | | - 9 | 3 | 24 | 18 | 90 | |
| 1536 | 10.8 | 11 04 18 | -58 02 31 | | | 17 | -43 | 17 | 5 | 22 | |
| 1537 | 9.1 | 11 04 06 | -58 02 57 | $-57^o4260$ | | - 7 | - 6 | 16 | 9 | 90 | |
| 1538 | 10.8 | 11 04 04 | -58 03 19 | | | -56 | 63 | 32 | 20 | 0 | |
| 1539 | 10.7 | 11 03 35 | -58 04 53 | | | 29 | - 2 | 18 | 13 | 72 | |
| 1540 | 10.8 | 11 03 20 | -58 02 35 | | | 13 | 37 | 22 | 8 | 59 | |
| 1541 | 9.7 | 11 03 14 | -58 05 17 | $-57^o4226$ | | 31 | -21 | 7 | 7 | 46 | |
| 1542 | 10.6 | 11 03 10 | -58 03 17 | $-57^o4225$ | | - 6 | 5 | 22 | 18 | 91 | |
| 1543 | 10.3 | 11 03 06 | -58 02 34 | $-57^o4219$ | | -62 | -33 | 8 | 10 | 0 | |
| 1544 | 9.7 | 11 03 01 | -58 06 14 | $-57^o4214$ | | - 7 | - 8 | 8 | 15 | 90 | |
| 1545 | 10.5 | 11 03 01 | -58 02 54 | $-57^o4216$ | | - 7 | 16 | 4 | 4 | 87 | |
| 1547 | 10.7 | 11 02 50 | -58 02 18 | | | 56 | -18 | 10 | 13 | 2 | |
| 1548 | 10.7 | 11 02 24 | -58 02 15 | | | -22 | -10 | 10 | 2 | 80 | |
| 1549 | 10.7 | 11 02 23 | -58 04 38 | | | - 4 | -12 | 19 | 13 | 89 | |
| 1550 | 10.8 | 11 02 21 | -58 02 03 | | | 4 | - 9 | 10 | 16 | 90 | 3 |
| 1551 | 10.3 | 11 02 12 | -58 03 27 | $-57^o4185$ | | 41 | - 7 | 12 | 15 | 35 | |
| 1552 | 10.8 | 11 01 58 | -58 05 23 | | | -55 | 11 | 20 | 16 | 4 | |
| 1553 | 10.8 | 11 01 37 | -58 03 24 | | | 35 | -22 | 15 | 17 | 33 | 3 |
| 1554 | 9.5 | 11 01 32 | -58 03 30 | $-57^o4159$ | | 30 | -31 | 4 | 11 | 28 | |
| 1555 | 9.5 | 11 01 16 | -58 03 41 | $-57^o4148$ | | - 9 | - 1 | 18 | 14 | 90 | |
| 1556 | 10.8 | 11 01 09 | -58 04 04 | | | 7 | - 2 | 18 | 28 | 91 | |
| 1557 | 10.7 | 11 00 42 | -58 03 15 | | | 5 | 5 | 8 | 10 | 91 | |
| 1558 | 10.8 | 11 00 32 | -58 01 38 | | | -86 | 38 | 16 | 14 | 0 | 2 |
| 1559 | 10.3 | 11 00 28 | -58 03 58 | $-57^o4125$ | | -36 | -45 | 7 | 7 | 6 | |
| 1560 | 9.1 | 11 00 25 | -58 06 13 | $-57^o4123$ | | 17 | - 7 | 9 | 8 | 85 | |
| 1561 | 10.8 | 11 00 18 | -58 05 22 | | | 80 | -27 | 22 | 17 | 0 | |
| 1562 | 10.8 | 11 00 14 | -58 04 25 | | | 17 | -57 | 6 | 22 | 3 | |
| 1563 | 9.5 | 11 00 01 | -58 05 06 | $-57^o4116$ | | -19 | - 6 | 13 | 11 | 84 | |
| 1564 | 10.8 | 10 59 53 | -58 05 03 | | | 68 | -48 | 24 | 25 | 0 | |
| 1565 | 10.3 | 10 59 45 | -58 02 39 | $-57^o4112$ | | - 5 | 1 | 13 | 18 | 91 | |
| 1566 | 10.7 | 10 59 43 | -58 02 13 | | | -29 | 40 | 10 | 18 | 17 | |

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# Stratigraphic and Igneous Units in the Rockvale-Coffs Harbour Region, Northern New South Wales

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ABSTRACT. A separate stratigraphic nomenclature is developed for three distinct structural blocks in the Rockvale - Coffs Harbour region of New South Wales, and several units are defined for the first time. In the western Rockvale Block the term Girrakool Beds replaces the invalid term Lyndhurst Beds. The Dyamberin Block, located between the Wongwibinda and Demon faults, is subdivided into the Dyamberin Beds and the Sara Beds. In the eastern Coffs Harbour Block the term Coffs Harbour Beds is discarded and the unit is subdivided into the Moombil Beds, Brooklana Beds and Coramba Beds. Four previously undescribed igneous intrusions from the Coffs Harbour Block are also defined.

## INTRODUCTION

The stratigraphy for most of the Rockvale - Coffs Harbour region is defined here for the first time, although some of the nomenclature has been introduced previously by Binns *and others* (1967) and by Leitch *et al.* (1971). The absence of fossils from most of the region, together with a lack of continuous outcrop and the inaccessibility of some districts, causes difficulties in determining detailed stratigraphic subdivisions. This note is an attempt to clarify the stratigraphic nomenclature of the region, over which there has been much confusion in recent years.

All major units are termed Beds rather than Formations, as recommended by the Australian Code of Stratigraphic Nomenclature (1973), because the relationships between some units have not been established conclusively. Most boundaries between units have not been observed in the field and hence their positions are only approximate. Further work involving detailed mapping of small areas may result in subdivision of the units described here and the raising of some of them to formational status. No type sections are defined but representative localities, displaying typical rocks, are listed for each unit.

The Rockvale - Coffs Harbour region has been subdivided into three structural blocks by Korsch (1975). The western Rockvale Block is separated from the central Dyamberin Block by the Wongwibinda Fault, and the eastern Coffs Harbour Block is separated from the Dyamberin Block by the Demon Fault. A different lithostratigraphy for each block has been proposed because each block has had a separate development during deposition and orogenesis, and is now exposed at different levels of erosion. Hence the stratigraphy of each block will be described separately. Figure 1 indicates the distribution of the blocks and stratigraphic units which are discussed below.

## STRATIGRAPHY OF THE ROCKVALE BLOCK

Rocks from this block have been divided into the low-grade metamorphosed sediments around Rockvale (here termed the Girrakool Beds) and the high-grade metamorphic rocks of the Wongwibinda Complex (see Binns, 1966).

### Girrakool Beds

Synonymy: Lyndhurst Beds, Binns (1966), Voisey and Packham (1969). Girrakool Beds, this note. According to the Australian Code of Stratigraphic Nomenclature (1973) the name Lyndhurst is invalid, it having been used for the Lyndhurst Formation (Coats, 1964) in South Australia.

Derivation: Girrakool homestead (GR 50082-408, Dorrigo 1:250 000).

Lithology: Indurated mudstone, siltstone and lithic to feldspathic greywacke derived from a volcanic source area.

Definition of Boundaries: The Girrakool Beds are intruded by the Hillgrove Adamellite in the south and by the Tobermory Adamellite and associated granitic plutons in the north. The beds become increasingly metamorphosed to the east until they are truncated by the Glen Bluff Fault. To the west unsuccessful efforts have been made by the author and others to define the contact between the Girrakool Beds and the Sandon Beds in the vicinity of Armidale. The line of contact seems to be defined only by gross changes in lithology, notably a rapid decrease in the amount of chert in passing from the Sandon Beds to the Girrakool Beds. There is no evidence for a major fault as inferred by Leitch *et al.* (1971) and the inferred line of contact appears to be parallel to bedding in the two units. However no exposure of the contact has been observed, and the contact may be transitional.

Representative Section: This unit is well exposed along Rockvale Creek from GR 49542449 to where the sediments are intruded by the Rockvale Adamellite-Granodiorite at GR 50002386, Dorrigo 1:250 000.

Thickness: A large area of the Girrakool Beds has been overturned and has suffered three deformations. The intense folding has made the defining of a section impracticable and hence no estimate of the thickness can be given. It is possible that a very thick sequence of sediments is present.

Age: R.J. Gunthorpe found fossil fragments near Rockvale homestead which were identified by

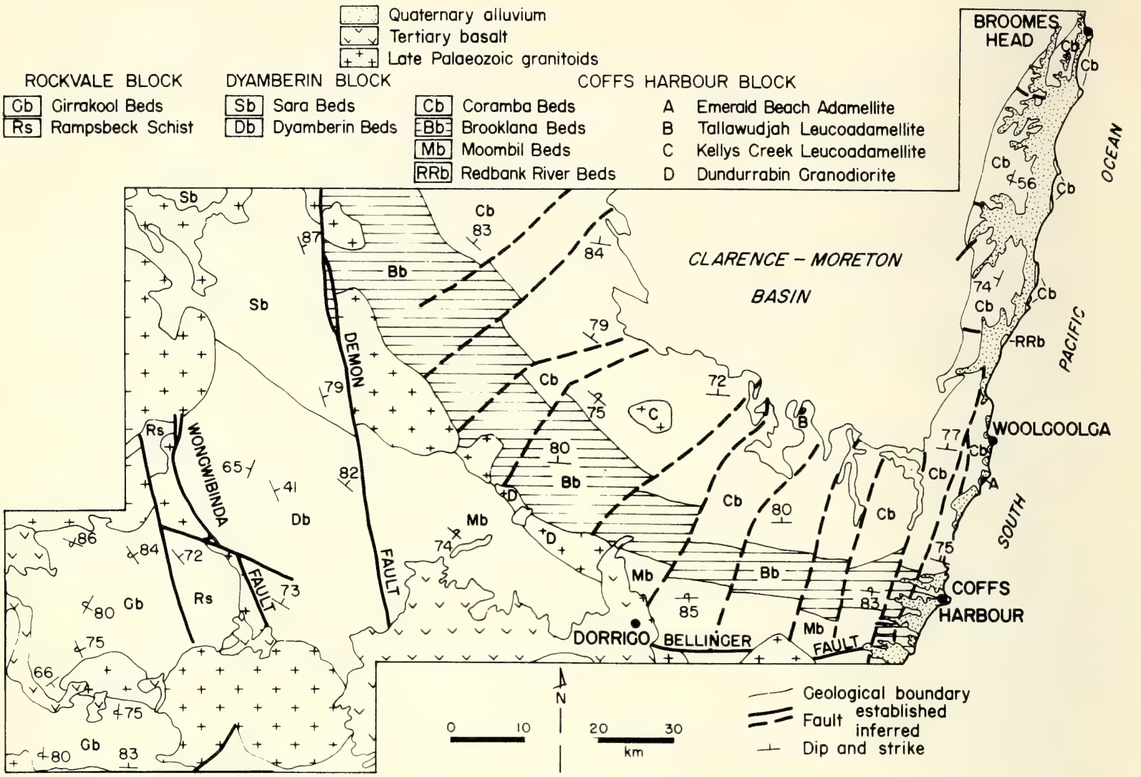


Fig. 1. Geology of the Rockvale - Coffs Harbour region, showing the distribution of the stratigraphic units and location of igneous intrusions.

Runnegar (1970) as *Atomodesma* sp. indicating a Permian age.

STRATIGRAPHY OF THE DYAMBERIN BLOCK

The Dyamberin Block has not been examined in detail previously, because it is rugged, heavily forested and of difficult access. It has been possible to subdivide this block into two conformable stratigraphic units. The older unit occurs to the south and the name Dyamberin Beds proposed by Binns (1966) is retained here. However, Binns did not define this unit. The northern, younger unit is here termed the Sara Beds.

Dyamberin Beds

Previous References: Binns (1966), Voisey and Packham (1969). Binns named the rocks immediately to the east of the Wongwibinda Fault but did not define the unit.

Derivation: Dyamberin homestead (GR 52592-568, Dorrigo 1:250 000).

Lithology: Interbedded greywacke, siltstone and mudstone with horizons of diamictite. In places the finer rocks show a well developed cleavage. Diamictite with either a sandy or muddy matrix is more abundant than orthoconglomerate. Voisey (1950) recorded tuff and acid lava flows.

Definition of Boundaries: The Dyamberin Beds are bounded on the west by the Wongwibinda Fault and on the east by the Demon Fault. To the south they are intruded by the Round Mountain Leucoadamellite and overlain by Cainozoic basalt. To the north they are conformably overlain by the Sara Beds. A typical contact of the Sara Beds and Dyamberin Beds is at GR 53472726, Dorrigo 1:250 000).

Representative Section: Along Kangaroo Creek from GR 52322568, Dorrigo 1:250 000 to its junction with the Aberfoyle River.

Thickness: Folding and slaty cleavage, and the absence of continuous outcrop hinders determination of thickness, but the steep north dip of bedding planes suggests a thickness of several thousand metres.

Age: The fossil locality at Kangaroo Creek (GR 52492622, Dorrigo 1:250 000) has been ascribed

a Permian age by Voisey (1950). Runnegar (1970) recollected the material and listed the following fossils, indicative of an Early Permian age (equivalent to the Allandale fauna of Runnegar, 1969):

*Deltopecten illawarensis* (Morris)
*Trigonotreta* Sp. A
*Fletcherithyris* sp. ind.
fenestrate polyzoans.

Sara Beds

Name and Derivation: New name, derived from the Sara River which flows eastwards from the New England Plateau until it joins the Guy Fawkes River at GR 53432911, Grafton 1:250 000.

Lithology: Orthoconglomerate horizons and associated siliceous mudstone, siltstone and greywacke derived from the erosion of volcanic rocks. Rare basic and acid volcanics occur also.

Definition of Boundaries: The Sara Beds are bounded on the east by the Demon Fault and to the north and west by granitic rocks of the New England Batholith *sensu stricto*. They conformably overlie the Dyamberin Beds to the south. The Sara Beds are characterised by orthoconglomerate and only contain rare diamictite, and hence can be readily distinguished from the Dyamberin Beds.

Representative Section: Good, although not continuous, exposures occur in the Guy Fawkes River in the vicinity of the junction with the Sara River from GR 53582884 to GR 53542949, Grafton 1:250 000.

Thickness: Not determined, but steep dip and wide outcrop width of beds, together with lack of evidence of changes in facing direction, indicate that a thick sequence is probably present.

Age: Structural relations indicate that the Sara Beds conformably overlie the Dyamberin Beds and hence it is assumed that they are also of Permian age. The only fossils found were crinoid stems at GR 53502734, Dorrigo 1:250 000 and in a loose boulder in the Guy Fawkes River.

STRATIGRAPHY OF THE COFFS HARBOUR BLOCK

Palaeozoic sediments of the Coffs Harbour Block have been subdivided previously into the Redbank River Beds and the Coffs Harbour Beds by Korsch (1971). Leitch *et al.* (1971) in compiling the Dorrigo - Coffs Harbour 1:250 000 Geological sheet introduced a three-fold subdivision of the Coffs Harbour Beds into the Moombil Beds, Brooklana Formation and Coramba Beds but they did not define their divisions. The present author is satisfied that the three units of Leitch *et al.* (1971) are recognisable subject to minor boundary changes, and hence it is proposed that the term Coffs Harbour Beds be abandoned in favour of the three-fold subdivision of Leitch *et al.* (1971). To clarify the situation the three units will be defined here.

Moombil Beds

Synonymy: Leitch *et al.* (1971). This unit was previously part of the Coffs Harbour Beds, the synonymy of which has been discussed by Korsch (1971).

Derivation: Mt Moombil (GR 59272448, Dorrigo 1:250 000).

Lithology: Black massive argillite with minor sandstone and siltstone. Bedding is rarely present and other sedimentary structures were not observed.

Definition of Boundaries: The lowermost part of this unit is faulted against the Nambucca Slate Belt of Leitch (1975). Structural evidence indicates a conformable relationship with the overlying Brooklana Beds, and the boundary between these units has been displaced in numerous localities by faulting.

Representative Section: Leitch (1972) considered that typical rocks are well exposed along the road leading to the summit of Mt Moombil.

Thickness: Indeterminate because of the massive nature of the lithologies and discontinuous outcrop. The steep dip and wide outcrop width of beds, together with lack of evidence of changes in facing directions, indicate a thick sequence is probably present.

Age: The Moombil Beds predate the possibly Late Palaeozoic Brooklana Beds.

Brookland Beds

Synonymy: Brooklana Formation (Leitch *et al.*, 1971). The name is revised in accordance with the Australian Code of Stratigraphic Nomenclature (1973) because no type section has been designated. This unit was previously part of the Coffs Harbour Beds. (For previous synonymy see Korsch, 1971.)

Derivation: Village of Brooklana (GR 59522-506, Dorrigo 1:250 000).

Lithology: Thin-bedded siliceous mudstone and siltstone with rarer sandstones. Dark highly-cleaved mudstones in beds from one cm to several metres thick occur interbedded with lighter coloured more siliceous rocks which may be finely laminated. Sandstones are more common than in the Moombil Beds.

Definition of Boundaries: No contacts were observed in the field but a conformable relationship between the Brooklana Beds and the underlying Moombil Beds and overlying Coramba Beds was deduced from structural evidence. The Brooklana Beds are distinguished from the Moombil Beds by the absence of black massive argillite, and from the Coramba Beds by the predominance of siliceous mudstone and siltstone over sandstone. A thin sliver of rocks similar to the Brooklana Beds occurs along the Demon Fault about 10 km south of Newton Boyd School.

Representative Section: Leitch (1972) considered the Brooklana Beds were characteristically exposed around the village of Brooklana. The type section for the rocks previously called Coffs Harbour Beds was the quarry and cliffs on the south side of the town of Coffs Harbour. These rocks occur within the Brooklana Beds and must be regarded as the representative section (GR 62542449, Coffs Harbour 1:250 000).

Thickness: Unknown, but because bedding dips

mainly steeply north, a sequence of several thousand metres is suggested.

Age: No fossils have been found but a Late Palaeozoic age is postulated on the tenuous basis of lithological correlation with sediments of known Late Palaeozoic age (e.g. Girrakool Beds).

Coramba Beds

Synonymy: Leitch *et al.* (1971) named this unit and indicated its areal extent but did not define it. The term Coramba Granite (Kenny, 1936) is here redefined to Coramba Beds because the rock described by Kenny is a very coarse-grained hornblende-bearing feldspathic sandstone and not a granite. This unit was previously part of the Coffs Harbour Beds, the synonymy of which has been discussed by Korsch (1971). The segment of the Coffs Harbour Beds described by Korsch (1971) corresponds to the Coramba Beds as defined here.

Derivation: Village of Coramba (GR 61222559, Coffs Harbour 1:250 000).

Lithology: Lithic and feldspathic greywacke derived from a volcanic source area, with minor siltstone, siliceous siltstone and mudstone. Calcareous siltstone and acid and basic volcanics are rare.

Definition of Boundaries: Structural evidence indicates that the Coramba Beds conformably overlie the Brooklana Beds and are unconformably overlain by the Clarence-Moreton Basin. No contacts were observed but the Coramba Beds are distinguished from the Brooklana Beds by the predominance of sandstone over siltstone and mudstone.

Representative Section: The Coramba Beds are typically exposed along the Coramba to Dorrigo road immediately west of Coramba village (GR 61222559, Coffs Harbour 1:250 000), (Leitch, 1972). Excellent exposures can be observed in the headlands along the coast such as Woolgoolga Headland (GR 63302692, Coffs Harbour 1:250 000).

Thickness: Unknown because of lack of continuous outcrop, mesoscopic folding and small scale reverse faults. A regionally consistent steep dip to the north suggests a thickness of several thousand metres.

Age: The only fossil found was a fragment of a polyzoan of unknown affinities at GR 62982770, Coffs Harbour 1:250 000. Attempts at conodont extraction from a calcareous siltstone have been unsuccessful. It is postulated that the age of the Coramba Beds is possibly Late Palaeozoic.

Igneous Intrusions

It is proposed to define three previously undescribed igneous intrusions in the Coffs Harbour Block, and one which has been named (Dundurrabin Granodiorite, Binns and others, 1967) but not formally defined.

Emerald Beach Adamellite

Synonymy: New name. This intrusion was described by Korsch (1971) but not named or defined at that stage.

Derivation: Coastal resort of Emerald Beach (GR 63052619, Coffs Harbour 1:250 000).

Lithology: Slightly-porphyritic medium-grained adamellite.

Definition of Boundaries: This is a small intrusion which occurs only at an unnamed headland between Bare Bluff and Signal Hill, and extends eastwards beneath the sea for an unknown distance. It intrudes the Coramba Beds producing biotite-grade hornfels.

Type Area: Unnamed headland between Bare Bluff and Signal Hill (GR 63112630, Coffs Harbour 1:250 000).

Age: Unknown, possibly Late Palaeozoic - Early Mesozoic.

Tallawudjah Leucoadamellite

Synonymy: New name, as intrusion was previously undescribed.

Derivation: Tallawudjah Creek, west of Glenreagh village. The creek cuts the intrusion at GR 60462738, Dorrigo 1:250 000.

Lithology: Porphyritic leucoadamellite with phenocrysts of white feldspar set in a fine-grained groundmass of feldspar, quartz and mafic minerals.

Definition of Boundaries: The intrusion has been emplaced into the Coramba Beds and its western boundary is covered by the Mesozoic Clarence-Moreton Basin sediments.

Type Area: The vicinity of Tallawudjah Creek where it cuts the intrusion.

Age: Unknown, but thought to be Late Palaeozoic because it intrudes the Coramba Beds and is covered by the Late Triassic Mill Creek Siltstone.

Kellys Creek Leucoadamellite

Synonymy: New name, as the intrusion was previously undescribed.

Derivation: Kellys Creek, which enters the Nymboida River in the western half of the pluton at GR 58192724, Dorrigo 1:250 000.

Lithology: Two textural variants of leucoadamellite occur: coarse-grained porphyritic rock with phenocrysts up to 10 mm in a fine-grained groundmass and, coarse to fine even-grained leucoadamellite.

Definition of Boundaries: The pluton intrudes the Coramba Beds and has produced a contact aureole of biotite-cordierite hornfels.

Type Area: The vicinity of Kellys Creek where it cuts the intrusion.

Age: Unknown, possibly Late Palaeozoic or Early Mesozoic.

Dundurrabin Granodiorite

Synonymy: Binns and others (1967) named this intrusion but did not define it.

Derivation: Village of Dundurrabin (GR 56222605, Dorrigo 1:250 000).

Lithology: Predominantly coarse- to medium-grained granodiorite and adamellite. Phenocrysts of K-feldspar occur frequently, and xenoliths are abundant in the coarse phases. Dioritic phases also occur.

Definition of Boundaries: The pluton intrudes the Moombil Beds and Brooklana Beds producing biotite-cordierite hornfels adjacent to the contacts.

Type Area: Road cuttings on the Grafton to Ebor road just to the east of Dundurrabin, and outcrops in the Blicks River where the road crosses the river.

Age: Unknown, possibly Late Palaeozoic.

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# The Geology of Brushy Hill, Glenbawn, New South Wales

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ABSTRACT. A finer subdivision of the strata at Glenbawn is proposed. The lowest exposed beds are distinguished as the Chateau Douglas Sandstone Member and contain a small conodont fauna suggesting an early Carboniferous age. The remainder of Oversby and Roberts' (1973) Kingsfield Beds, accorded formation status as the Kingsfield Formation, lacks marine fossils and consists in part of red sediment for which non-marine conditions of sedimentation are proposed. Conformably overlying the non-marine sediments is a newly distinguished unit, the Macqueen Formation characterised by a fauna dominated by bivalves, gastropods and rhynchonellid brachiopods. This unit was previously included as the base of Oversby and Roberts' (1973) Dangarfield Formation. Barrier sands of the Wroxley Lithic Sandstone Member (new name) overlain by the Brushy Hill Limestone Member comprise the basal units of the conformably overlying Dangarfield Formation.

The large vertical displacement across the Brushy Hill Fault, in the order of 1000 m, is a result of remobilisation of a pre-existing NNW trending fault, subsequent to all other deformational events in the area.

## INTRODUCTION

This paper presents an account of the early Carboniferous sedimentary sequence within Brushy Hill, covering about 15 km$^2$ on the western foreshores of Lake Glenbawn, near Scone, in the Hunter Valley, N.S.W. (Fig. 1). The area lies near the western margin of a zone of N to NNW trending folds and faults (Basin belt of Voisey, 1959, Zone "A" of Leitch, 1974) delineated by the Hunter-Mooki Thrust to the west and the Peel Fault to the east.

The earliest published work including the area of the present study, was that of Osborne (1928) on the Rouchel District. It was later incorporated in a regional synthesis of the Hunter-Manning-Myall province (Osborne, 1950).

The construction of Glenbawn Dam in the fifties was preceded by a limited amount of geological mapping largely restricted to the site of the dam wall, an account of which was published by Wilson and Scott (1957).

In 1970 Branagan *et al.* published a short informal description of the stratigraphy of the Glenbawn area. In another short communication Oversby and Roberts (1973) revised the stratigraphic succession and proposed formal names for rock units. In the same year a more detailed palaeogeography than previously reconstructed in Packham (1969) was published by these authors. Later (in 1974) Roberts and Oversby reiterated and expanded upon their work of the previous year.

In the present study the recognition of a finer subdivision of the stratigraphic sequence within Brushy Hill has led to modifications of the formal names proposed by the previous workers. Table I compares the previous nomenclature used in the area with that of this paper.

## KINGSFIELD FORMATION

The Kingsfield Formation, previously the Kingsfield Beds (Oversby and Roberts, 1973), exposed over an area of 4 km$^2$ within Brushy Hill is the stratigraphically lowest formation in the area. The unit comprises 160 m of largely reworked crystal tuffs composed of fragments of complexly twinned plagioclase and embayed quartz, intercalated with red beds.

The top of the Kingsfield Formation is redefined as the highest occurrence of purple or red beds in any locality rather than the highest red shale in the type section (GR 113 454) as proposed by Roberts and Oversby (1974) because that particular bed cannot be traced further than 250 m south from the type section. The presence, in the overlying Macqueen Formation, of specimens of *Siphonodella* sp. similar to those found in the basal member of the Kingsfield Formation suggests that if any break in sedimentation occurred between the deposition of the fossiliferous layers it was of short duration. While the Kingsfield Formation is equivalent to the Kingsfield Beds of Oversby and Roberts (1973) described in the text of their paper, their map, however, shows the boundary between the Kingsfield Beds and overlying Dangarfield Formation to coincide with the top of the Macqueen Formation, which overlies the Kingsfield Formation as defined and mapped in this paper.

Unit 1 of Branagan *et al.* is defined as a member at the base of the Kingsfield Formation and given the name Chateau Douglas Sandstone Member after the nearby Chateau Douglas estate. The type locality of the member is situated 150 m south of the airstrip (GR 115 432) where there is the only relatively continuous vertical section, 10 m thick, through the unit (Fig. 2, section 5). The lowermost 8 m exposed consists of coarse angular lithic sandstone with scattered volcanic pebbles. Two

<table>
<tr><th colspan="2">Branagan et al. 1970<br>(after figure 3)</th><th colspan="2">Oversby and Roberts 1973<br>(after figure 2)</th><th colspan="2">This paper</th></tr>
<tr><td>Unit<br>6</td><td>Lithology<br>Conglomerate-volcanic sequence</td><td colspan="2">Isismurra Formation</td><td colspan="2">Isismurra Formation</td></tr>
<tr><td>5</td><td>Mudstone crinoidal-coral limestone sequence</td><td></td><td rowspan="4">Dangarfield Formation</td><td></td><td rowspan="3">Dangarfield Formation</td></tr>
<tr><td>4</td><td>Oolitic limestone sequence</td><td>Brushy Hill Limestone Member</td><td>Brushy Hill Limestone Member</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Lithic sandstone sequence</td><td rowspan="2"></td><td>Wroxley Lithic Sandstone Member</td></tr>
<tr><td colspan="2">Macqueen Formation</td></tr>
<tr><td colspan="2" rowspan="3">Kingsfield Beds</td><td colspan="2" rowspan="2">Kingsfield Formation</td></tr>
<tr><td>2</td><td>Volcanic sequence</td></tr>
<tr><td>1</td><td>Sandstone & ironstone</td><td>Chateau Douglas Sandstone Member</td><td></td></tr>
</table>

TABLE I

COMPARISON OF THE STRATIGRAPHIC DIVISIONS OF PREVIOUS WORKERS TO THOSE OF THIS PAPER (NOT TO SCALE)

metres from the base calcareous nodules are dispersed through the lithic sandstone. The early Tournaisian (Early Carboniferous) conodont *Siphonodella* sp. has been recovered from nodules 150 m north along strike at the same level (GR 114 434). The excellent preservation of the fragile specimens argues against significant transportation and thus indicates a marine depositional environment for at least the lower beds of the Chateau Douglas Sandstone Member.

Outcrop is so poor that it is impossible to determine, even at the type locality, whether or not the boundary between the lithic sandstone and the overlying magnetite sandstone within this member is gradational or sharp. The magnetite-rich sandstone contains up to 70% rounded to subrounded magnetite grains with minor lithic fragments in a chlorite-rich matrix. To explain this concentration of heavy minerals Roberts and Oversby (1974) considered the magnetite-rich sandstone to represent reworking in a beach or related environment.

The axial location of the Chateau Douglas Sandstone Member within the Brushy Hill Anticline (Osborne, 1950) accounts for the small area, 0.4 $km^2$, over which it is exposed and the non-exposure of its base. The upper boundary of the Member is defined as the last occurrence of magnetite-rich sandstone and the first appearance of dacitic tuffs and lavas.

While the type section below the dam wall (GR 110 453 - 113 454) of the Kingsfield Beds of Oversby and Roberts (1973) provides good exposures of the uppermost 70 m of the unit, there is a gap of approximately 80 m between the Chateau Douglas Sandstone Member and the lowest beds in the type section. This gap is largely due to the discontinuity of outcrop south of the type section where the lowermost 90 m of the formation is exposed, and the lack of suitable marker horizon to correlate away from the type section. In the type section the sequence is dominated by dacite derivatives, mainly reworked felsic tuffs usually with minor lithic fragments and cross-bedded crystal tuffs with a hematite matrix. The crossbeds indicate a current direction predominantly from the west.

Except for rare vascular plants found in the top 10 m and the conodonts near the base, the Kingsfield Formation is otherwise barren of fossils. The lack of marine fossils and the presence of red beds in the upper part of the formation suggest a non-marine environment of deposition; the uppermost purple tuffaceous shale

in the type section has been interpreted as of possible intertidal or alluval overbank origin by Roberts and Oversby (1974). A basic igneous intrusion at this level in the type section has obliterated the internal bedding and any associated sedimentary structures thus creating difficulties in assessing either interpretation.

MACQUEEN FORMATION

The type section of the Macqueen Formation (new name), below the wall of the Glenbawn Dam (GR 113 454 - 114 455) comprises 64 m of lithic sandstones and siltstones grading into calcareous skeletal mudstones and wackestones (*sensu* Dunham, 1962) with subordinate lithic sandstone. The formation takes its name from the County of Macqueen which encompasses the greater part of Brushy Hill.

The lower contact of the Macqueen Formation in the type section is at the top of red beds of the Kingsfield Formation. The upper contact in the type section is the stratigraphically highest occurrence of calcareous skeletal mudstones and wackestones, which are abruptly overlain by massive, relatively unfossiliferous lithic sandstone and minor mudstone at the base of the overlying formation.

The macrofauna of the Macqueen Formation is a restricted assemblage of marine invertebrates dominated by thin walled mytiliform bivalves, rhynchonellid brachiopods and gastropods. Brachiopod and bivalve shells are often articulated and, as with the gastropod shells, are most common in the fine grained rocks. Shelly material is absent from the basal 10 m of the formation where lithic sandstone is more common than higher in the sequence. In the lowest beds the concentration of carbonaceous material in the siltstones and the lack of a shelly fauna suggest that sediment was derived from an environment analagous with modern intertidal or supratidal mangroves.

Conodonts, as well as fish teeth and plates, are rare in the Macqueen Formation, having been recovered only from calcareous concretions in the upper beds. The conodonts consist entirely of a dwarfed or juvenile fauna of *Siphonodella* sp., apparently the same species as that found in the lower beds of the Chateau Douglas Sandstone Member. While only platform elements are represented, the wide size range of associated fish teeth suggests that the dwarfed fauna is not a result of selective bottom sorting.

Preservation of the macrofauna, due to both depositional and post-depositional events, is generally poor. On the same horizon preservation varies from articulated to fragmented, with the angularity of shell fragments suggesting that little transport had taken place. The fragmentation of shells may have been the result of predation, but no remains of a possible predator were found; the shells showed no signs of boring. A more likely explanation is that sporadic periods of agitation during storm activity at the site of deposition resulted in the breakup of shells and poor sorting of fragments. Because the majority of the thin walled shells of this formation are usually complete, but contorted, much of the inferior preservation can be attributed to compaction of the enclosing fine grained sediments.

Towards the top of the Macqueen Formation there are a number of massive unfossiliferous lithic sandstone beds, similar to those of the overlying Wroxley Member. At the southern end of Brushy Hill on the eastern limb of the anticline, lithic sandstone is dominant within the Macqueen Formation, shelly material being present only in thin beds at the base and top of the unit. On the western limb the uppermost 45 m of the formation is exposed in a cliff section on the bank of Rouchel Brook (Figure 2, Section 3). Here, massive lithic sandstone is also dominant but shelly material is a little more common than in the east and is restricted to thin beds of calcareous skeletal mudstone and wackestone. These sections contrast strongly with those farther north where lithic sandstones constitute only a small proportion of the unit.

The largely fine grained nature of the sediments in this unit, the apparent lack of continuous periods of agitation at the site of deposition and the generally delicate nature of the skeletal material suggest a near-shore protected environment such as a lagoon or protected embayment open to the sea. Fragmentation of shells may have resulted from storm activity and possibly predation. Relatively unfossiliferous thin lithic sandstone beds within the unit may represent influxes of sands from nearby environments.

DANGARFIELD FORMATION

The Dangarfield Formation was previously defined by Oversby and Roberts (1973) as the thick sequence of mudstone and subordinate lithic sandstone and oolitic and crinoidal limestones overlying the tuffs and tuffaceous sandstones of the Kingsfield Beds. In the present paper the name is restricted to the sequence overlying the Macqueen Formation, itself newly distinguished as a separate unit. The basal contact is between the highest calcareous skeletal mudstones and wackestones of the Macqueen Formation and rarely fossiliferous massive lithic sandstone of the lowest member of the Dangarfield Formation. The upper contact with the overlying Isismurra Formation lies outside the Brushy Hill area here described and has been defined by Oversby and Roberts (1973, p. 198).

Two members, the Wroxley Lithic Sandstone Member (new name) and the Brushy Hill Limestone Member are recognised at the base of the formation, underlying a thick predominantly mudstone sequence. The Wroxley Lithic Sandstone Member is named after Wroxley homestead, 2.5 km south-west of the Glenbawn Dam. In the type section next to the dam wall (GR 113 456 - 114 456) it comprises 62 m of monotonous massive lithic sandstone with minor mudstone. The lower contact in the type section is marked by unfossiliferous calcareous lithic sandstone abruptly overlying calcareous skeletal mudstones and wackestones of the Macqueen Formation. The upper contact, where exposed, is nearly always gradational with the overlying Brushy Hill Limestone Member. The gradational nature is produced

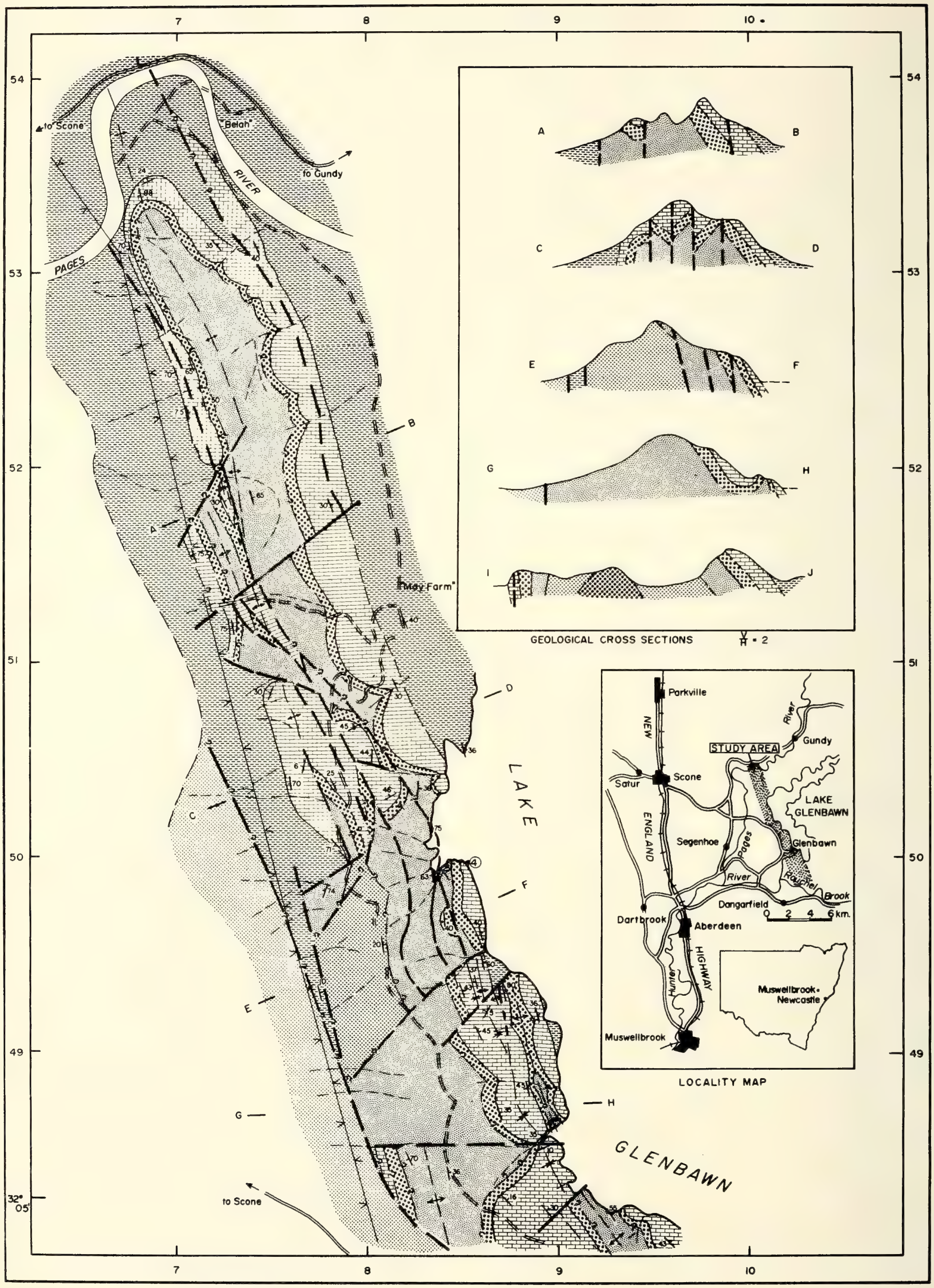


Fig. 1(a) Geology of the Brushy Hill Area, Glenbawn.
Fig. 1(b) adjoins at the base of Fig. 1(a).

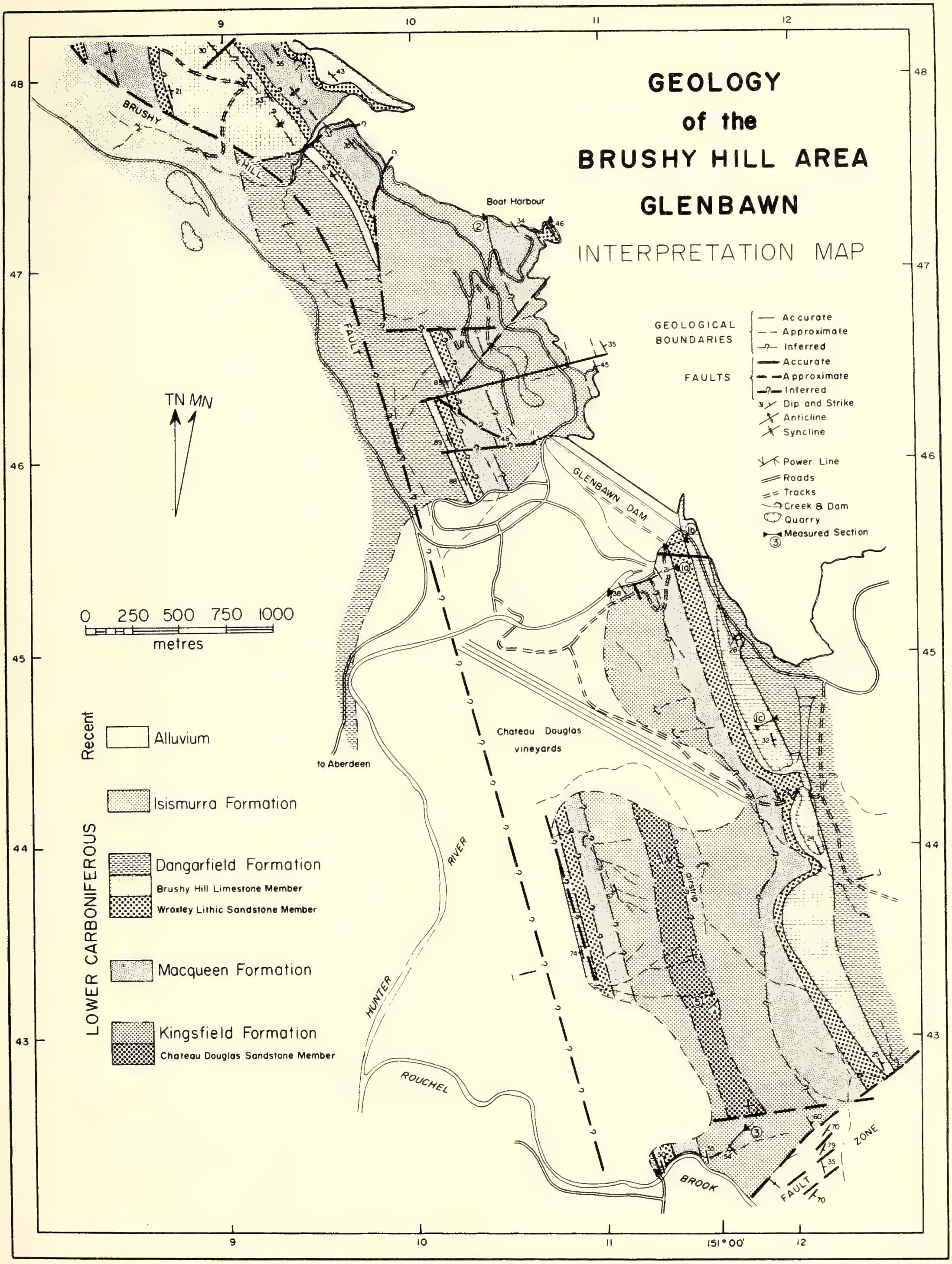


Fig. 1(b) Geology of the Brushy Hill Area, Glenbawn.
Fig. 1(a) adjoins at the top of Fig. 1(b).

by the increasing proportion of ooliths to uncoated lithic fragments found with ascent through the strata.

Within the Wroxley Member fossils are rare, consisting largely of broken and worn fragments of marine invertebrates, mainly crinoid ossicles. Worn disoriented specimens of *Lithostrontion williamsi* Pickett, *Syringopora septatisiphon* Pickett and *Naoides rangariensis* Pickett were found in a calcareous pebble sandstone 14 m below the top of the member at GR 085 500 (Figure 2, Section 4). The stratigraphic position of this member between near-shore protected marine sediments below and an oolitic facies above suggests that it was deposited as a barrier bar.

The Brushy Hill Limestone (Osborne, 1950) was placed within the Dangarfield Formation by Oversby and Roberts (1973). In the type section located in the large quarry south of the dam wall (GR 118 460) this member consists of 22 m of thinly crossbedded oolith and skeletal grainstones with minor mudstone. Generally the contact with the underlying Wroxley Lithic Sandstone Member is gradational, but in the large limestone quarry it is marked by a lithic sandstone bed with oolith grainstones above and lithic grainstone below. The upper contact is defined by the abrupt change between skeletal oolith grainstone and the overlying monotonous brown and grey mudstone. In the vicinity of the type section this contact is also marked by a large number of disoriented solitary rugose corals and disarticulated brachiopods.

In the large limestone quarry the Brushy Hill Limestone Member can be divided into three levels which are not only lithologically distinct but are separated by two mudstone beds (note: these subdivisions are not shown in Figure 2). The lower beds in the type section consist of 9 m of thinly crossbedded oolith grainstones. Crossbeds were observed to dip not only to the east but also to the west indicating a strong tidal influence. Ooliths at this level comprise well over 90% of the allochems and are typically small, less than 0.33 mm in diameter. Macrofauna is sparse with only rare worn crinoid ossicles present. Above the lower beds about 3 m of massive skeletal oolith grainstone constitutes the middle beds. Here the ooliths are up to 0.5 m in diameter. Away from the large limestone quarry these beds are indistinguishable from the upper beds of this unit. The upper beds of the Brushy Hill Limestone Member in the type section consist of 9 m of thinly bedded oolith and skeletal grainstones. Ooliths, which constitute between 10% and 80% of the allochems, are typically large (up to 1.25 mm in diameter) with a relatively small nucleus. The diverse and abundant invertebrate fauna present at this level, make up the rest of the allochems.

In the lower beds of the Brushy Hill Limestone Member ooliths constitute well over 90% of the allochems, a composition best compared with that of modern oolite shoals (Purdy, 1964). The low taxonomic diversity of the lower beds is consistent with sediments on a shoal or reworked from such a shoal with little invading macrofauna. The upper beds appear to be analgous to outer platform sediments or the mixed oolite facies of modern Bahamian oolite shoals where the sediment is largely derived from the shoal and supports a diverse fauna of invading invertebrates.

Variations in the nature of the ooliths from small thinly coated lithic grains in the lower beds to larger thickly coated grains in the upper beds reflects a decreasing supply of lithic sands to the oolite shoal allowing ooliths to grow over a longer period. It may be that the oolite shoal developed directly from barrier sands similar to those of the Wroxley Lithic Sandstone Member with fewer such grains becoming available for coating as the oolite shoal widened in extent. The absence of ooliths in the Macqueen Formation also points to an oolite shoal developing subsequently to barrier sands because the lagoonal facies adjacent to modern oolite shoals contains a high ooid content caused by the relative strength of the flood tide over the ebb tide (Purdy, 1964).

Conformably overlying the Brushy Hill Limestone Member a thick sequence of brown and grey mudstones with minor crinoid coral limestones, conglomerate and lithic sandstones comprises the remainder and major part of the Dangarfield Formation. The abrupt lithological change from grey/blue skeletal oolith grainstone, into brown and grey mudstones, with a disoriented fauna of solitary rugose corals and brachiopods suggests the sudden influx of the enclosing muds. Pyrite lined worm burrows in the numerous calcareous concretions above the Brushy Hill Limestone indicate reducing conditions during the deposition of the muds in contrast to the presumably well oxygenated conditions in the oolite facies.

DEPOSITIONAL HISTORY

Deposition of shallow water near-shore marine sands and magnetite-rich beach sands took place during the early Carboniferous forming the Chateau Douglas Sandstone Member. Subsequently volcanic and volcanically derived sediment accumulated in a non-marine environment; this sediment now comprises the remainder of the Kingsfield Formation. Following the end of non-marine sedimentation marine sedimentation commenced with transgression from the east. Basal carbonaceous siltstones and lithic sandstones of the Macqueen Formation may have been deposited in a marginal marine environment. Protected near-shore marine conditions prevail for the remainder of this unit as inferred from calcareous skeletal mudstones and wackestones containing a restricted fauna of rhynchonellid brachiopods, mytiliform bivalves and gastropods. These carbonates pass southwards into lithic sandstones indistinguishable from those of the conformably overlying Wroxley Lithic Sandstone Member.

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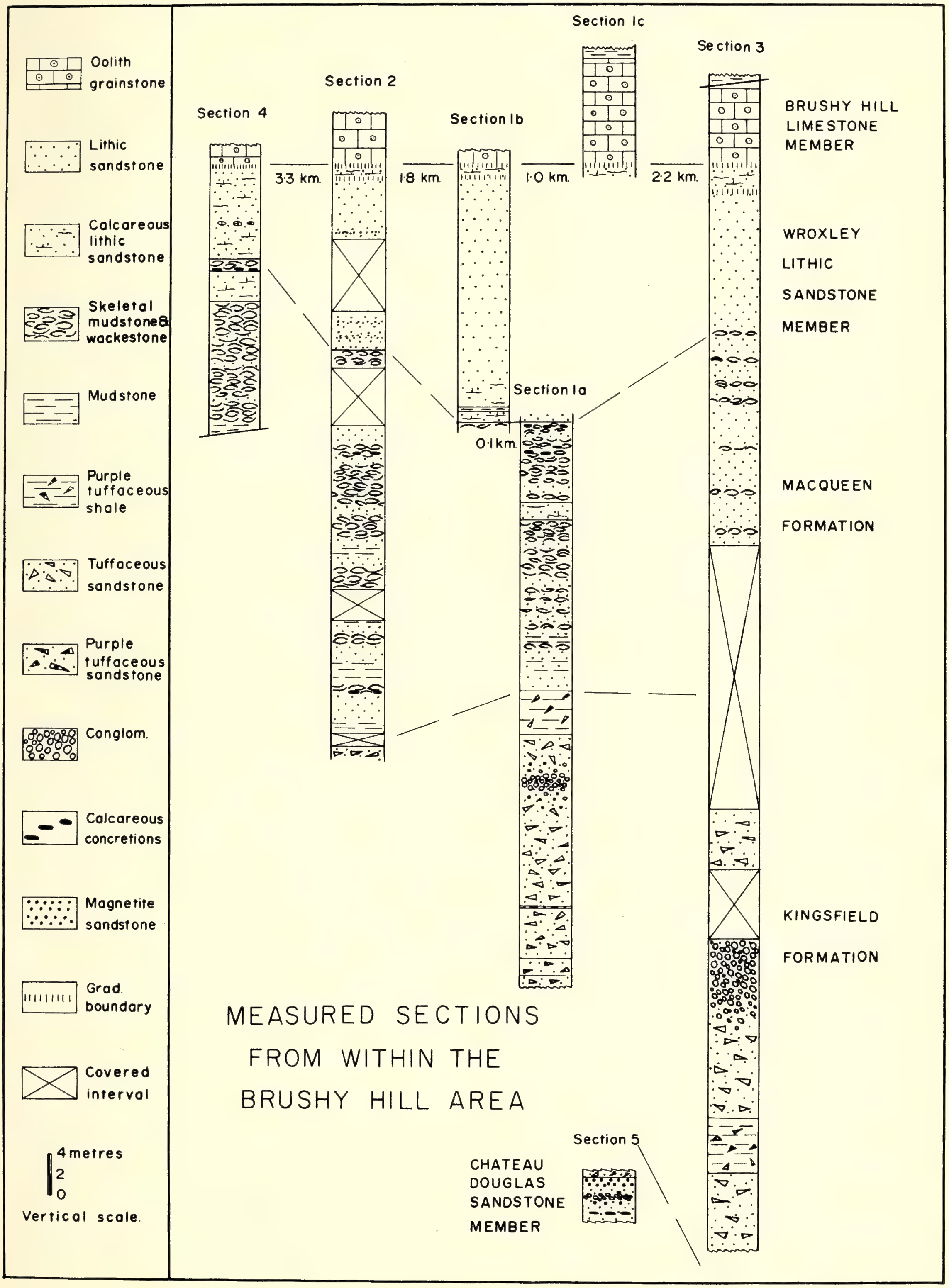
Fig. 2: Measured sections from within the Brushy Hill area.

Sections 1(a), 1(b), 1(c) and 5 are type sections of the Macqueen Formation, the Wroxley Lithic Sandstone Member, the Brushy Hill Limestone Member and the Chateau Douglas Sandstone Member respectively.




MEASURED SECTIONS FROM WITHIN THE BRUSHY HILL AREA

The poorly fossiliferous massive lithic sandstone of the latter unit is interpreted as having been deposited as barrier sands from its stratigraphic position between protected near-shore carbonates and an oolitic limestone. Increase in the proportion of ooliths relative to uncoated lithic grains towards the top of this unit indicates the development of an oolite shoal offshore from the barrier bar. Transgression continued during the deposition of the Brushy Hill Limestone Member with the oolite facies widening in extent as fewer lithic grains became available for coating.

STRUCTURE OF BRUSHY HILL

Brushy Hill consists of two *en-echelon*, asymmetrical concentric, NNW trending anticlines with steeply dipping western limbs. Faults trending to the NNE, E and NE, named the Brushy Hill Trend, the Davis Creek Trend and the Woolooma Trend respectively by Oversby and Roberts (1973), cut the anticlines (Fig. 3).

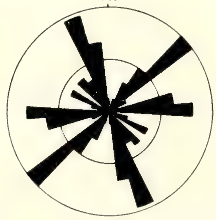



Fig. 3: Analysis of the 36 faults in Brushy Hill using 10° intervals.

The structure, previously named the Brushy Hill Anticline (Osborne, 1950) is non-cylindrical, consisting of several folds displaying variations in plunge over small distances, especially in the northern half of Brushy Hill. The overall trend of the fold nose axes is 17° plunging towards 347° (Fig. 4) with the variation being 0° to 35° N towards the N to NW. In the southern half of Brushy Hill the single anticline forming the Brushy Hill structure displays a near horizontal axis.

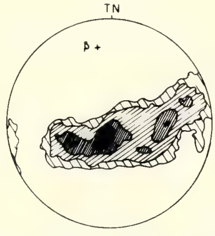



Fig. 4: 600 poles to bedding from 10 fold noses within Brushy Hill. 1, 2, 4, 6% contours per 1% area. $\beta$: 17° → 348.

In the northern half of Brushy Hill two asymmetric concentric anticlines with steeply dipping and occasionally overturned western limbs are separated by a tight asymmetric concentric syncline. The syncline and western anticline are restricted to the northern half of Brushy Hill being truncated by the Brushy Hill Fault (Osborne, 1928) just north of the Brushy Hill road (GR 084 480).

Some NNW trending faults in the northern end of Brushy Hill appear to peter out towards fold axes of approximately the same bearing (e.g. at GR 077 505 and GR 087 493) suggesting a genetic relation between the two.

In Figure 1 the crosscutting faults, which postdate the fold axes and NNW trending faults, are shown as displaced by the Brushy Hill Fault. Decisive observation is prevented by extensive soil cover. The inferred relationship is largely based on the work of Roberts and Oversby (1974) who show that the well defined NE trending faults at the southern end of Brushy Hill near Rouchel Brook abut against the Brushy Hill Fault near Dangarfield. The NE trending crosscutting faults evident just north of Rouchel Brook do not displace the resistant ignimbrite ridge of the Isismurra Formation 1.5 km to the SW.

The Brushy Hill Fault, which brings the Isismurra Formation against the stratigraphically lowest units (Macqueen and Kingsfield Formations) on the western side of Brushy Hill, is sigmoidally shaped, trending between NNW and WNW with a vertical displacement in the order of 1000 m. This displacement contrasts strongly with the NNW trending faults to the east, within Brushy Hill, which have displacements generally less than 100 m. No direct evidence can be seen for horizontal movement along the Brushy Hill Fault, nor can its inclination at depth be determined by surface geological methods in the area mapped.

Previous workers in the area have related the steeply dipping nature of the western limb of the Brushy Hill Anticline to its proximity to the Brushy Hill Fault (Branagan *et al.*, 1970; Oversby and Roberts, 1973; Roberts and Oversby, 1974). This relationship infers that the folding and the initial movement along the Brushy Hill Fault were part of the same episode (Marshall, 1974). This inference apparently conflicts with the relationship implied by the Brushy Hill Fault truncating the two western fold axes and the cross cutting faults. The apparent conflict is best explained by remobilisation of an already established NNW trending fault. It is suggested that only one phase of strong compressional stress perhaps followed by an episode of tensional stress affected the Glenbawn area. Both phases were presumably within the Hunter-Bowen Orogeny, the only known major orogeny affecting the area. The large displacement across the Brushy Hill Fault appears to represent the last deformational event in the area although no evidence exists in the Brushy Hill area for the post-Triassic age Osborne (1950) assigned to this movement.

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# A q-Expansion Formula

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ABSTRACT. An extension of a q-expansion formula of Carlitz is obtained for an analytic function, and is illustrated by some simple special cases.

## INTRODUCTION

Carlitz (1973) proved the q-expansion formula:

$$f(z) = \sum_{n=0}^{\infty} \frac{z^n \, [\Delta_x^{n+m}\{\Delta_x^{-m} f(x)\cdot(x)_n\}]_{x=0}}{(q)_n (z)_{n+m+1}}, \tag{1}$$

where $f(z)$ is an analytic function of $z$ about $z = 0$; $m$ is a non-negative integer; $(q)_n = (1-q)(1-q^2)(1-q^3)\ldots(1-q^n)(n>0)$, $(q)_0 = 1$; $(z)_n = (1-z)(1-qz)(1-q^2z)\ldots(1-q^{n-1}z)(n>0)$, $(z)_0 = 1$; operators $\Delta_x$ and $\Delta_x^{-m}$ are defined as:

$$\Delta_x f(x) = \frac{1}{x}\{f(x) - f(qx)\},$$

and

$$\Delta_x^{-m} \sum_{n=0}^{\infty} \frac{a_n x^n}{(q)_n} = \sum_{n=m}^{\infty} a_{n-m} \frac{x^n}{(q)_n}.$$

Carlitz remarks that the formula (1) reduces to

$$f(z) = f(0) + \sum_{n=1}^{\infty} \frac{z^n \, [\Delta_x^{n-1}\{\Delta_x f(x)\cdot(x)_n\}]_{x=0}}{(q)_n (z)_n} \tag{2}$$

for $m = -1$, and gives an independent proof of this formula. In the present paper we shall establish a general formula which gives (2) as a special case.

## DERIVATION

In this section we shall prove the following formula:

$$f(z) = \sum_{n=0}^{m-1} [\Delta_x^n f(x)]_{x=0}\cdot\frac{z^n}{(q)_n} + \sum_{n=m}^{\infty} \frac{z^n \, [\Delta_x^{n-m}\{\Delta_x^m f(x)\cdot(x)_n\}]_{x=0}}{(q)_n (z)_{n-m+1}}, \tag{3}$$

where $m$ is a non negative integer, $|q| < 1$, $|z| < 1$; $f(z)$ is an analytic function of $z$ about $z = 0$; $(q)_0 = 1$, $(q)_n = (1-q)(1-q^2)(1-q^3)\ldots(1-q^n)(n>0)$; $(z)_0 = 1$, $(z)_n = (1-z)(1-qz)(1-q^2z)\ldots(1-q^{n-1}z)$; operator $\Delta_x$ is defined as:

$$\Delta_x f(x) = \frac{1}{x}\{f(x) - f(qx)\}.$$

### Proof

Since $f(z)$ is an analytic function of $z$ about $z = 0$, we have

$$f(z) = \sum_{n=0}^{\infty} \frac{a_n z^n}{(q)_n}. \tag{4}$$

Therefore

$$\Delta_x^m f(x)\cdot(x)_n = \left(\sum_{n=0}^{\infty} a_{n+m} \frac{x^n}{(q)_n}\right)\left(\sum_{k=0}^{n} \frac{(-1)^k (q)_n q^{\frac{1}{2}k(k-1)}}{(q)_k (q)_{n-k}} x^k\right)$$

since

$$(x)_n = \sum_{k=0}^{n} \frac{(-1)^k (q)_n q^{\frac{1}{2}k(k-1)}}{(q)_k (q)_{n-k}} x^k$$

Rearranging the above result we get

* communicated by W.E. Smith

$$\Delta_x^m f(x)\cdot(x)_n = \left[\sum_{t=0}^{n} \sum_{k=0}^{t} \frac{(-1)^k (q)_n q^{\frac{1}{2}k(k-1)}}{(q)_k (q)_{n-k}} \cdot \frac{a_{t+m-k}}{(q)_{t-k}} x^t\right.$$

$$\left. + \sum_{t=n+1}^{\infty} \sum_{k=0}^{n} \frac{(-1)^k (q)_n q^{\frac{1}{2}k(k-1)}}{(q)_k (q)_{n-k}} \cdot \frac{a_{t+m-k}}{(q)_{t-k}} \cdot x^t\right].$$

Thus we get

$$[\Delta_x^{n-m}\{\Delta_x^m f(x)\cdot(x)_n\}]_{x=0} = \sum_{k=0}^{n-m} (-1)^k \left[{n \atop k}\right]\left[{n-m \atop k}\right] (q)_k q^{\frac{1}{2}k(k-1)} a_{n-k},$$

where

$$\left[{n \atop k}\right] = \frac{(q)_n}{(q)_k (q)_{n-k}} .$$

Putting n-m = N we get

$$[\Delta_x^{N}\{\Delta_x^m f(x)\cdot(x)_{m+N}\}]_{x=0} = \sum_{k=0}^{N} (-1)^k \left[{m+N \atop k}\right]\left[{N \atop k}\right] (q)_k q^{\frac{1}{2}k(k-1)} a_{m+N-k}. \qquad (5)$$

This formula admits of a simple inverse, namely

$$a_{m+N} = \sum_{k=0}^{N} \left[{N \atop k}\right]\left[{m+N \atop k}\right] (q)_k [\Delta_x^{N-k}\{\Delta_x^m f(x)\cdot(x)_{m+N-k}\}]_{x=0}. \qquad (6)$$

which is an instance of the equivalence of

$$y_n = \sum_{k=0}^{n} (-1)^k \left[{n \atop k}\right]\left[{n+m \atop k}\right] (q)_k q^{\frac{1}{2}k(k-1)} x_{n-k}$$

and

$$x_n = \sum_{k=0}^{n} \left[{n \atop k}\right]\left[{n+m \atop k}\right] (q)_k\, y_{n-k},$$

where m is a fixed non-negative integer.

From (6) we have

$$\sum_{N=0}^{\infty} a_{m+N} \frac{z^{N+m}}{(q)_{N+m}} = \sum_{N=0}^{\infty} \frac{z^{n+m}}{(q)_{N+m}} \sum_{k=0}^{N} \left[{N \atop k}\right]\left[{N+m \atop k}\right] (q)_k [\Delta_x^{N-k}\{\Delta_x^m f(x)\cdot(x)_{m+N-k}\}]_{x=0}$$

$$= \sum_{k=0}^{\infty} \sum_{N=0}^{\infty} \frac{z^{N+m+k}}{(q)_{m+N}} \left[{N+k \atop k}\right][\Delta_x^{N}\{\Delta_x^m f(x)\cdot(x)_{m+N}\}]_{x=0}$$

$$= \sum_{N=0}^{\infty} \frac{z^{N+m}}{(q)_{N+m}} [\Delta_x^{N}\{\Delta_x^m f(x)\cdot(x)_{m+N}\}]_{x=0} \cdot \frac{1}{(z)_{N+1}}$$

$$(|q| < 1,\ |z| < 1).$$

Replacing N by n-m we get

$$\sum_{n=m}^{\infty} \frac{a_n z^n}{(q)_n} = \sum_{n=m}^{\infty} \frac{z^n[\Delta_x^{n-m}\{\Delta_x^m f(x)\cdot(x)_n\}]_{x=0}}{(q)_n\,(z)_{n-m+1}}$$

or,

$$f(z) = \sum_{n=0}^{m-1} [\Delta_x^n f(x)]_{x=0} \frac{z^n}{(q)_n} + \sum_{n=m}^{\infty} \frac{z^n[\Delta_x^{n-m}\{\Delta_x^m f(x)\cdot(x)_n\}]_{x=0}}{(q)_n\,(z)_{n-m+1}}$$

If we take m=1 we get (2).

## SPECIAL CASES

The function e(z) is defined as:

$$e(z) = \prod_{n=0}^{\infty} (1 - q^n z)^{-1} \qquad (|q| < 1,\ |z| < 1).$$

We also know the formulas:

$$e(z) = \sum_{n=0}^{\infty} \frac{z^n}{(q)_n}$$

and

$$\frac{e(z)}{e(az)} = \sum_{n=0}^{\infty} \frac{(a)_n}{(q)_n} z^n \qquad \text{(Carlitz 1976).}$$

Using these results we get some results as special cases of the formula (3).

For $f(z) = z^s$ $(s \geq m)$ we have from (3),

$$z^s = \sum_{n=s}^{\infty} (-1)^{n-s} \begin{bmatrix} n-m \\ n-s \end{bmatrix} q^{\frac{1}{2}(n-s)(n-s-1)} \frac{z^n}{(z)_{n-m+1}} \qquad (s \geq m,\ m \geq 0). \tag{7}$$

For $f(z) = e(z)$ we have from (3),

$$e(z) = \sum_{n=0}^{m-1} \frac{z^n}{(q)_n} + \sum_{n=m}^{\infty} \frac{z^n q^{n(n-m)}}{(q)_n (z)_{n-m+1}} \qquad (m \geq 0,\ |z| < 1,\ |q| < 1) \tag{8}$$

or

$$\sum_{n=0}^{\infty} \frac{z^n}{(q)_{n+m}} = \sum_{n=0}^{\infty} \frac{z^n q^{n(n+m)}}{(q)_{n+m} (z)_{n+1}} \qquad (m \geq 0,\ |z| < 1,\ |q| < 1). \tag{9}$$

For $f(z) = \frac{e(z)}{e(az)}$ we have from (3),

$$\frac{e(z)}{e(az)} = \sum_{n=0}^{m-1} \frac{(a)_n z^n}{(q)_n} + \sum_{n=m}^{\infty} \frac{z^n (a)_m (-a)^{n-m} \left(\frac{q}{a}\right)_{n-m} q^{\frac{1}{2}(n-m)(n+m-1)}}{(q)_n\ (z)_{n-m+1}} \tag{10}$$

$$(m \geq 0,\ |z| < 1,\ |q| < 1)$$

or

$$\sum_{n=0}^{\infty} \frac{(a)_{n+m}}{(q)_{n+m}} z^n = \sum_{n=0}^{\infty} \frac{z^n (a)_m (-a)^n \left(\frac{q}{a}\right)_n q^{\frac{1}{2}n(n+2m-1)}}{(q)_{m+n}\ (z)_{n+1}} \tag{11}$$

$$(m \geq 0,\ |z| < 1,\ |q| < 1).$$

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# A Carboniferous Echinoid Archaeocidaris SP. Indet. From New South Wales

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ABSTRACT. A specimen of *Archaeocidaris* sp. indet. from the Lower Carboniferous of New South Wales is illustrated and described.

Fossil echinoids are extremely rare in the Palaeozoic rocks of Australia. Brown (1967) has described a Lower Devonian lepidocentroid as *Cavanechinus warreni*. Thomas (1967) illustrated *Oligoporous* (?) sp. from the Carboniferous of Western Australia and Etheridge (1892) described and illustrated two species of *Archaeocidaris* of Permian age from New South Wales. Other records of Australian Palaeozoic echinoids are based on indeterminate fragments (cf. Brown, 1967).

The Carboniferous echinoid recorded here was collected by I. Lavaring from Mt Breakneck, Carrow Brook district, southern New England (Camberwell Military Map 000313) N.S.W. and is lodged in the Australian Museum (F58896). It is from the *Rhipidomella fortimuscula* Zone of early Carboniferous (late Visean) age.

It is a poorly preserved flattened internal mould which, however, shows the essential characters of the genus *Archaeocidaris*. The interambulacra consist of four columns of plates each presumably bearing a large primary tubercle. There are two columns of simple plates in each sinuous ambulacrum with approximately ten plates opposite each ambital interambulacral plate. The test was clearly imbricate, although the junctions between plates are not strongly bevelled. The apical system which is now lost was apparently very wide (Fig. 2). The lantern is preserved, but only the distal ends of the demipyramids are visible (Fig. 3). The distal slides are extremely wide, implying the presence of shovel-shaped teeth.

*Archaeocidaris* is particularly well represented in the Carboniferous of Europe and North America. As was pointed out by Jackson (1912) its test characters are extremely conservative, the various species being distinguished in the character of the radioles. Until more material becomes available more detailed comparisons are not possible.

I am obliged to Dr. Alex Ritchie who passed on the specimen for examination, and Mr. Richard Sealy who prepared the illustrations.

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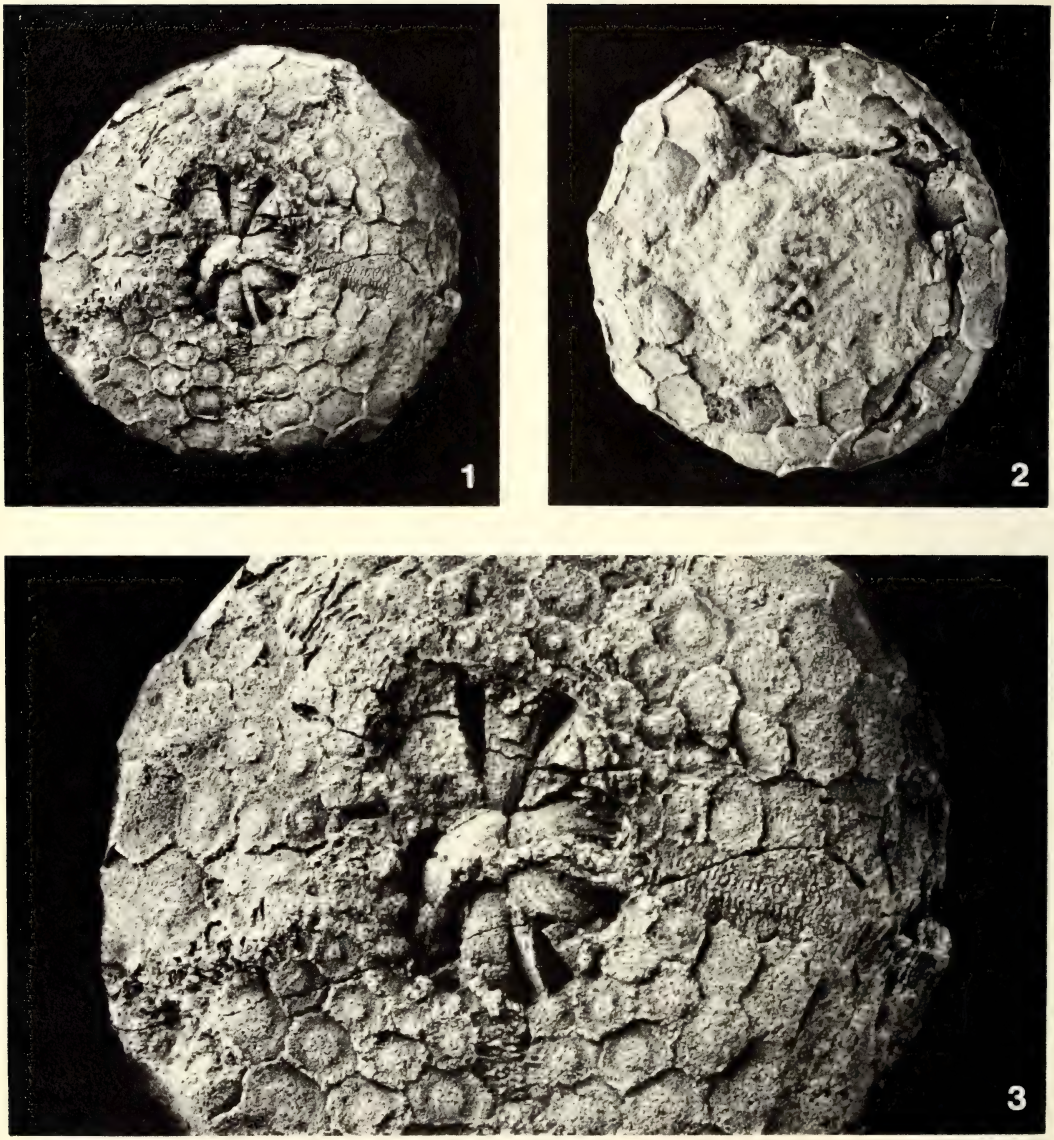

*Archaeocidaris* sp., Australian Museum F58896; *Rhipidomella fortimuscula* Zone: Mt Breakneck, Carrow Brook district, southern New England, N.S.W.

Fig. 1. Oral view, x 3/4.

Fig. 2. Apical view, x 3/4

Fig. 3. View of Aristotle's lantern, x 1 1/2

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# Silurian Conodonts from Blowclear and Liscombe Pools, New South Wales

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ABSTRACT. Conodont assemblages indicate a Late Llandoverian age for the Liscombe Pools Limestone, and a Middle Ludlovian age for strata probably referable to the Milpose Volcanics.

## INTRODUCTION

During the course of the preparation of a correlation table for Silurian strata in N.S.W., many samples of limestone from areas of Silurian outcrop within the State were treated for conodonts. Yields from almost all of these were either nil, or so low that the faunas recovered were useless for purposes of age diagnosis. The two assemblages discussed in this article represent rare exceptions. One of them was mentioned briefly by Percival (1976).

The major work on Silurian conodonts in N.S.W. is that of Link and Druce (1972); other reports are those of Cooper (1977), De Deckker (1976), Bischoff (*in* Talent et al. 1975), Nicoll and Rexroad (1974), Owen et al. (1974) and Whaite & Whaite (1972).

## Assemblage A

The assemblage was obtained from a limestone considered to be a lens in the Millambri Formation by Ryall (1965), but more recently named the Liscombe Pools Limestone by Percival (1976). The sample was taken at GR 181844, Bathurst 1:250,000 sheet, just north of the crossing on Licking Hole Creek. Percival recognised a disconformity between the limestone and the underlying Millambri Formation; from near the top of the latter he records *Glyptograptus tamariscus* Nicholson, *Monograptus jonesi* Rickards, *Pseudoclimacograptus (Metaclimacograptus) hughesi* (Nicholson), *P. (M) undulatus* (Kurck) and *P. (Clinoclimacograptus) retroversus* Bulman and Rickards, taken as indicating a Middle Llandovery age, most probably in the zone of *M. gregarius*. The limestone itself contains an abundant macrofauna, chiefly corals and stromatoporoids, including *Halysites cratus* Eth. f., *Halysites gamboolicus* Eth. f., *Liscombea insolens* Phillips, *Favosites* spp., *Multisolenia* sp. and heliolitids. The following disjunct conodont species have been recognised, the more distinctive of which are illustrated on plate 1:

*Astropentagnathus irregularis* Mostler
*Aulacognathus kuehni* Mostler
*Diadelognathus excertus* (Nicoll & Rexroad)
*Distacodus obliquicostatus* Branson & Mehl
*Distomodus curvatus* Rhodes?
*Distomodus kentuckyensis* Branson & Branson
*Distomodus* sp.
*Exochognathus caudatus* (Walliser)
*Ligonodina ? variabilis* Nicoll & Rexroad
*Ligonodina* sp.
*Lonchodina walliseri* Ziegler
*Neoprioniodus excavatus* (Branson & Mehl)
*Neospathognathodus celloni* (Walliser)
*Neospathognathodus latus* Nicoll & Rexroad
*Neospathognathodus pennatus* (Walliser)
*Ozarkodina adiutricis* Walliser
*Ozarkodina adiutricis?* Walliser? (*sensu* Nicoll & Rexroad 1968)
*Ozarkodina media* Walliser
*Panderodus simplex* Branson & Mehl
*Panderodus staufferi* Branson, Mehl & Branson
*Roundya detorta* Walliser
*Trichonodella trichonodelloides* (Walliser)
*Trichonodella* sp.

The multi-element genera represented in this assemblage would include *Llandoverygnathus* (*sensu* Walliser 1972), *Oulodus* (*sensu* Sweet & Schönlaub 1975), ?*Distomodus* (*sensu* Jeppsson 1972), possibly *Delotaxis* and *Walliserodus* (*sensu* Cooper 1975) and of course *Astropentagnathus* and *Aulacognathus*. It is obvious that many elements must be missing from the assemblage, if indeed all these genera are represented.

The assemblage is referable to the *Icriodella inconstans* zone of Aldridge (1972), the *Neospathognathodus celloni* assemblage zone of Nicoll and Rexroad (1968), or the *celloni*-Zone of Walliser (1964). According to Mostler (1967) *Astropentagnathus* and *Aulacognathus* are characteristic of the lower *celloni*-Zone; Aldridge's (1972) results from the British Silurian indicate a horizon near the middle of his *Icriodella inconstans* assemblage zone, which on his correlation is equivalent to late *celloni*-Zone. Altogether the similarity of the assemblage is with samples Gullet 1 - 3, Gullet 4 and Hollybush of Aldridge, all from the Telychian C-5 division of the British Llandovery. Fifteen of the twenty-three forms from the present assemblage occur in one or more of those samples. The Telychian division C-5 has been tied to the graptolite zone of *Monograptus greistoniensis* (Jones et al. 1969). Although there is a general similarity to the British assemblages, the presence of *Neospathognathodus latus* and the branched form of *Ozarkodina adiutricis* may be indicative of North American affinity. This latter form was reported by Nicoll and Rexroad (1968, p. 49) as probably pathological. In the present sample it is represented by two large specimens, while there is only a single specimen of the normal *O. adiutricis*.

Conodont faunas of approximately similar age have been reported by Nicoll & Rexroad (1974); the presence of *Ozarkodina gaertneri* and *Pterospathodus amorphognathoides* implies a slightly younger age, although older elements are also present in the assemblage (*Ambalodus galerus, Apsidognathus*

*tuberculatus, Astrognathus* cf. *tetractis* and *Pygodus lyra*). This mixed fauna appears to be similar to that reported by Bischoff (*in* Talent et al. 1975) from the Rosyth Limestone Member at Borenore; Bischoff records a zone in which assemblages include forms from both the *celloni-* and *amorphognathoides*-Zones, below the *amorphognathoides*-Zone proper.

Assemblage B

The geology of the area in which the second sample was collected is still imperfectly elucidated. The locality lies below the unconformity at the base of the Late Devonian Hervey Group sediments on the eastern limb of the Tullamore Syncline, at GR 599922, Narromine 1:250,000 sheet, about 25 km east of Trundle. Outcrops are poor in the area, particularly to the east of the line of outcrop of the Hervey Group. On the Narromine sheet (Brunker 1972) the locality is shown as Early Devonian Trundle Beds; more recent mapping a short distance to the south (Bowman 1976) suggests that it is sediments associated with the Late Silurian Milpose Volcanics. The latter situation would be more in accord with the age suggested by the conodonts.

The only additional palaeontological evidence bearing on the age is that of Foldvary (1970), who described, as *Cheirurus (Crotalocephalus) regius*, a trilobite from a locality about 1.5 km to the south of the present locality, and probably more or less on strike with it. Foldvary considered the age of the locality to be Eifelian, on the basis of a presumed correlation with beds of that age further west; a correlation of the trilobite and conodont localities is by no means established.

In addition to the conodont elements listed below, the limestone at this locality includes a small fauna of tabulate corals (*Syringopora, Favosites,* thamnoporids) and brachiopods. Disjunct conodont elements include the following forms:

*Distomodus curvatus* Rhodes
*Distomodus curvatus* var. *dentatus* Rhodes
*Distomodus suberectus* Rhodes
*Drepanodus* sp.
*Hindeodella confluens* Branson & Mehl
*Hindeodella* sp.
*Lonchodina* sp.
*Neoprioniodus bicurvatus* (Branson & Mehl)
*Neoprioniodina* sp. nov.
*Ozarkodina typica* Branson & Mehl
*Panderodus unicostatus* (Branson & Mehl)
*Plectospathodus elegans* Rhodes
*Rotundacodina dubia* (Rhodes)
*Spathognathodus primus* (Branson & Mehl)
*Trichonodella* sp.

In terms of whole apparatuses, the assemblage clearly represents the species *Ozarkodina confluens, Distomodus dubius* and probably *Ligonodina excavata excavata* (Branson & Mehl) *sensu* Jeppsson (1972); that other species were present is indicated by the presence of panderodids and in particular by the presence of an N-element, so far undescribed.

The assemblage is closely similar to that described from the Aymestry Limestone by Rhodes (1953), eight of the thirteen elements reported occurring there as well. *O. confluens* in Britain ranges from the top of the Wenlock Limestone through the whole of the Ludlow and into the Downtonian; elements of *Distomodus dubius* do not appear until the upper Bringewoodian (Mid-Ludlovian) according to Aldridge (1975). The Aymestry Limestone is correlated with the Bringewood Beds (Middle Ludlow) by Ziegler et al. (1974).

The P-elements of *O. confluens* are similar to those of the $\alpha$-morphotype described by Klapper and Murphy (1974). This occurs in Nevada in that part of the Roberts Mountains Formation correlated with the upper *ploeckensis-, siluricus-* and *latialatus*-Zones of the Cellon profile of Walliser (1964). The same morphotype occurs in the Bainbridge Formation in Missouri, at a horizon within the *siluricus*-Zone (Rexroad and Craig 1971). At neither of these occurrences is there *Distomodus dubius,* but it is uncertain if this is of stratigraphic significance.

*Ozarkodina confluens* is known to accompany *Distomodus dubius* in the *siluricus*-Zone on Gotland, and in Scania to range from that zone into the base of the *eosteinhornensis*-zone (Jeppsson 1969, 1972). According to Jeppsson, there is evidence that *D. dubius* prefers deeper water (at least for the larger specimens) as it is more abundant in the shalier sequences of Scania than on Gotland, while the reverse seems to be the case for *O. confluens*. There is some support for this from local material, as the P-element of *O. confluens* in the Yass succession is known from only three specimens from the Bowspring and Euralie Limestone Members, which are probably the shallowest horizons in that part of the section within its range, while elements of *Distomodus* are much more widespread (Cliftonwood Limestone to Yarwood Siltstone Member) (Link & Druce 1972).

*Ozarkodina confluens* has recently been described from the Yarrangobilly Limestone (Cooper 1977) from a horizon similar to that of the present assemblage. It was absent from De Deckker's (1976) samples from the Kildrummie Formation.

In summary, assemblage B indicates an age between the latest *ploeckensis-* and earliest *eosteinhornensis*-zones, probably in the lower part of this range. In terms of the British stages this is mid-Ludlovian; upper Laidlaw Formation or Silverdale Formation in the Yass succession.

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EXPLANATION OF PLATE 1

All Illustrations x 30

Originals of Figures 1-21 from possible Milpose Volcanics, 25 km east of Trundle, GR 599922, Narromine 1:250,000 sheet. Originals of Figures 22-34 from Liscombe Pools Limestone, GR 181844, Bathurst 1:250,000 sheet, just north of the crossing over Licking Hole Creek.

Figures 1-21 are named using apparatus taxonomy; Figures 22-34 are named as single elements.

Figures 1-9

*Ozarkodina confluens* (Branson & Mehl). 1, outer lateral view of P element MMMC01402; 2, inner lateral view of P element MMMC01390; 3, aboral view of P element MMMC01385; 4, inner lateral view of O element MMMC01391; 5, outer lateral view of O element MMMC01403; 6, inner lateral view of $A_1$ element MMMC01393; 7, inner lateral view of N element MMMC01398; 8, inner lateral view of $A_2$ element MMMC01392; 9, inner lateral view of $A_3$ element MMMC01397.

Figures 10-17

*Distomodus dubius* (Rhodes). Homologies of the component elements are incompletely worked out, so no terminology is applied. 10, inner lateral view of MMMC01400; 11, 12, inner and outer lateral views of MMMC01404; 13, oblique view of MMMC01388; 14, inner lateral view of MMMC01394; 15, inner lateral view of MMMC01399; 16, outer lateral view of MMMC01387; 17, outer lateral view of MMMC01395.

Figures 18-19

*Ligonodina excavata excavata* (Branson & Mehl). *sensu* Jeppsson 1972. 18, inner lateral view of "hi element" MMMC01401; 19, inner lateral view of "pl element" MMMC01389.

Figure 20

Unassigned N element MMMC01396, inner lateral view.

Figure 21

Unassigned N element MMMC01386, inner lateral view.

Figures 22-23

*Exochognathus caudatus* (Walliser). 22, oblique view of MMMC01406; 23, lateral view of MMMC01412.

Figures 24-25

*Neospathognathodus pennatus* (Walliser). 24, oral, and 25, lateral views of MMMC01411.

Figure 26

*Neospathognathodus celloni* (Walliser). Oral view of MMMC01409.

Figure 27

*Ozarkodina adiutricis* Walliser. Outer lateral view of MMMC01410.

Figure 28

*Aulacognathus kuehni* Mostler. Oral view of MMMC01408.

Figure 29

*Astropentagnathus irregularis* Mostler. Oral view of MMMC01407.

Figure 30

Unidentified element, oral view, MMMC01416.

Figure 31

*Neospathognathodus latus* Nicoll & Rexroad. Oral view of MMMC01414.

Figure 32

*Diadelognathus excertus* Nicoll & Rexroad. Oblique aboral/internal view of MMMC01405.

Figure 33

*Trichonodella trichonodelloides* (Walliser). Inner lateral view of MMMC01413.

Figure 34

*Ozarkodina adiutricis ?* Walliser (*sensu* Nicoll & Rexroad, 1968). Inner lateral view of MMMC01415.


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Journal and Proceedings, Royal Society of New South Wales, Vol. 111, pp. 41-47, 1978

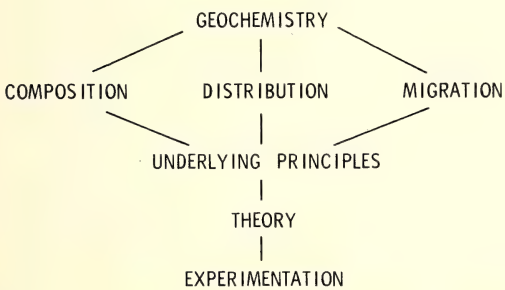
# Lead in the Environment*

D. J. SWAINE

ABSTRACT. Various aspects of the geochemistry of lead are discussed in terms of the geochemical cycle. Values are given for concentrations of lead in rocks, soils, water, vegetation, coals, and fertilisers. Lead tends to be concentrated in surface soils, probably because of the insolubility of the common lead minerals and of the lead complexed with some forms of organic matter. The same properties also govern the general unavailability of lead to plants and the low concentrations of lead in natural waters. Lead in solution in waters and lakes also depends on reactions at the sediment-water interface and on the pH and oxidation-reduction potential. The mean content of lead in coal is about 10 ppm Pb, and most of this is retained with fly-ash after the combustion of pulverised coal. The sources of lead in the body are also discussed. Pollution is seen as something imposed on a natural background; the proper assessment of the effects of lead and other heavy metals depends on reliable geochemical data and on careful interpretation.

## INTRODUCTION

Recently, while listening to Smetana's symphonic poem, Vltava, an idea occurred to me of how to approach the subject of this address. Just as he based his music on the progress of the river from the mountains to the plains, I will base this address on the journey, so to speak, of lead in the environment. This approach is in keeping with V.I. Vernadsky's description of geochemistry as the history of terrestrial atoms. The tasks of geochemistry, as envisaged by V.M. Goldschmidt, cover a wide range, as shown in the following scheme:




The attainment of an understanding of the geochemistry of an element requires an interdisciplinary approach, chemistry, geology and biology being especially important. This is shown in a recent study of lead in the environment (Boggess and Wixson, 1977). Any consideration of an element in nature should be made against the broad background of what is known about the geochemistry of that element. Lead will be used as an example of the general approach to the geochemistry of any element.

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* *Presidential address delivered to The Royal Society of New South Wales at the Science Centre, Clarence Street, Sydney, on 6 April 1977.*

## GEOCHEMICAL CYCLE OF LEAD

An abridged form of the geochemical cycle of lead is given in Fig. 1. Lead occurs in rocks either as a discrete mineral or for example, in

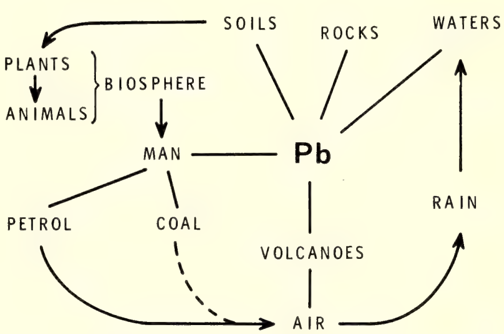


Fig. 1. Geochemical cycle of lead

feldspars and micas where the lead ion $Pb^{2+}$ may replace the potassium ion $K^+$ of similar ionic radius. Although there are more than 200 minerals of lead, few are common; probably the most important economically are galena (PbS), cerussite ($PbCO_3$), and anglesite ($PbSO_4$). During weathering, lead moves into soils and waters, albeit in minute amounts. Some lead is assimilated by vegetation and eventually by animals. In addition to natural sources, man is exposed to lead from various industrial sources, an important one being the combustion of petrol containing a lead antiknock additive. In this connexion, it should be noted that coal-burning contributes less than 0.5 per cent of the lead emitted to the atmosphere by the combustion of petrol. It seems that volcanoes and other natural sources release less lead to the atmosphere than man's activities. Rain scavenges lead from the air and returns it to the earth's surface.

TABLE 1
LEAD CONTENTS IN NATURAL MATERIALS

| | Lead content (ppm Pb) |
|---|---|
| ROCKS | |
| Basaltic | 6 |
| Granitic | 17 |
| Shales | 20 |
| Sandstones | 7 |
| Carbonates | 9 |
| SOILS | 2 - 200 |
| WATER | |
| River | 0.0006 - 0.12 |
| Ocean | 0.00003 |
| PLANTS | 0.1 - 30 |
| COALS | up to 60 |

Although it is difficult to generalise by calculating mean values for lead in various earth materials, such figures do give some idea of the order of the levels to be expected in many cases. Values (as parts per million Pb) taken from several publications are given in Table 1, those for rocks being mean values (Swaine, 1955, 1975; Lovering, 1976). Most values referred to in this address will be given as parts per million (ppm), 1 ppm being equivalent to 0.0001 per cent or 1 ug/g or 1 g/tonne, or for dilute aqueous solutions 1 mg/ℓ. The mean value for lead in the continental crust, known as the clarke, is 13 ppm Pb. For soils developed on granitic rocks in the north-east of Scotland the mean value is 15-20 ppm Pb, close to that for many granites. In general, oils have less lead than coals, the mean contents being less than 1 and about 10 ppm Pb respectively. Results for a suite of basaltic rocks (dolerites) from north-east Ireland were less than 10 ppm Pb (Patterson and Swaine, 1957), while samples of granites from the Aar-massif in Switzerland had 10-30 ppm Pb (Hügi and Swaine, 1963) in keeping with the generalisations of Table 1.

The low concentrations of lead in natural waters are a consequence of the gradual removal of lead from rocks and soils in relatively small amounts, and the insolubility of most of the common lead minerals and of lead complexed with some forms of organic matter; some lead is also removed by sorption on particulate matter. The very low value for ocean water probably refers to deep offshore waters, slightly higher values (up to a few micrograms per litre) being reported for surface and inshore waters.

The range of values for plants is not surprising. In general, the uptake of metals by plants depends on several factors, including the pH and moisture of the soil, and the species of plant. There are also seasonal effects and the metal content varies within the plant, often being highest in leaves. The range of values for coals refers to most of the published values, higher levels being associated with the presence of increased amounts of galena (PbS).

LEAD IN SOILS

During the formation of a soil some lead will be derived from the parent rock and may be taken up by plants, eventually being returned to the soil in decay products from the plants. Natural accumulation was found in uncultivated, organic-rich surface soils in north-east Scotland; in one soil, the surface (20-70 mm) had 550 ppm Pb compared with 30 ppm at a depth of 100-150 mm and in the parent rock. Another interesting example of the accumulation of lead in the surface of a soil was found in a rudimentary soil in Caenlochan Glen, Angus, Scotland, remote from industrial and agricultural influences (Swaine, unpublished). The material was coarse and was taken from a ledge on a crag, 800 m above sea level, the vegetation being small shrubs of the *Dryas* species. The -2 mm fraction had 100 ppm Pb in the surface layer (0-20 mm) compared with 10 ppm Pb in the underlying material (20-170 mm) and 10 ppm Pb in the unweathered parent rock (calcareous schist). In general, the lead content of most soils is in the range 2-200 ppm Pb (Swaine, 1955), with a mean of about 20 ppm.

It seems that lead in plant residues is fixed in the surface soil, possibly as an insoluble lead-organic matter complex or as a lead sulphate, a basic lead carbonate, or a lead phosphate. In the original soil, lead was probably partly in the crystal lattice of minerals like feldspars and partly adsorbed on clay minerals, iron oxides and manganese oxides. A decrease in pH to give acid conditions would favour the release of lead in a form which could become more available to some plants. Also, as shown by Swaine and Mitchell (1960), many elements, including lead, are mobilised in poorly-drained soils, and this may favour increased uptake by plants. This mobilised lead may be lead released from iron and manganese oxides and even clays under reducing conditions which favour desorption. A measure of easily-mobilised lead is gained by extracting soil samples with dilute acetic acid (0.5 N). For soils from north-east Scotland, levels of this soluble lead varied from a maximum of about 2 ppm Pb in freely-drained surface soils to a maximum of about 6 ppm Pb in the lower horizons of poorly-drained soils. It is clear that the main factors affecting changes in availability to plants of several trace elements adsorbed on clays and the like are pH and oxidation-reduction potential. Zones of accumulation of lead and certain other elements occur in some peat deposits, possibly because of mobilisation from nearby poorly-drained soils. Impeded drainage in swamps, prior to coal-formation, may have favoured the movement of lead and other trace elements and also increased the uptake by plants.

In general, the parent rock material is the source of lead in soils, but pedogenic factors during soil formation give rise to a distribution of lead in the soil profile, often culminating in accumulation in the surface. Climatic and topographic effects and the activities of micro-organisms modify the chemical processes of soil formation. Hence, there are general guidelines to aid the assessment of the lead status of soils, but detailed investigations are often needed for soils developed on various parent materials in particular locations. This may be important for a proper appraisal of the effects of air-borne or water-borne pollution on soils. In many cases, lead added to soils from external sources will be immobilised.

LEAD IN VEGETATION

Although lead is found in vegetation, it has not yet been shown to have a role in plant nutrition. The uptake of lead by plants depends on various factors mentioned earlier. A decrease in pH to acid conditions favours dissolution of lead from soil minerals and that adsorbed on clays and iron and manganese oxides, but lead associated with organic matter may remain relatively unavailable to plants. Under some conditions, phosphate-deficient plants may accumulate lead. During plant growth there is a translocation of lead within the plant, which may produce quite different concentrations of lead in different parts of the plant. For example, in a study of a grass (cocksfoot, *Dactylis glomerata*), Davey and Mitchell (1968) found at the flowering stage about 4 ppm Pb in the leaf, 1 ppm in the sheath and less than 1 ppm in the stem, values being in dry-matter.

The uptake of lead is likely to be greater on mineralised areas than on unmineralised areas, and mining activities may also increase the availability of lead to some plants. Such areas are small and are not used for agriculture. Just as chelation does not always mean increased solubility or availability, so increased solubility of lead *per se* does not necessarily mean increased availability to plants. Although extraction tests with acids and the like are often useful guides to the availability of metals to plants, the only sure way of ascertaining the uptake by plants is to analyse specimens from a particular area or to do pot experiments or plant trials under relevant conditions. Some species can thrive on soils with higher-than-normal lead. There are changes in lead contents of the various parts of plants during the growing season, an important factor to be considered when sampling plants for analysis. In some cases there are variations in different parts of the leaf, as shown in Fig. 2 for a eucalyptus leaf (Pickering, 1975).

It is well established that vegetation growing near roads has increased contents of lead, derived from motor-car exhausts, but it is not known precisely whether the lead is taken up from the soil or directly from the air into the leaves. There are certainly finely-divided particles of lead compounds on the surfaces of plants growing near busy roads, in keeping with the fact that lead bromo- and chloro-compounds are emitted from car exhausts. It should be noted that diesel fuel is not leaded. It is necessary to wash samples of vegetation before determining lead and before eating fruit or vegetables grown near busy roads.

Curtin *et al.* (1974) showed that metal complexes, including lead, are given off by vegetation during growth, but the extent and the importance of this in the geochemical cycle have not been established. Ferguson and Bubela (1974) carried out experiments with suspensions of algae and aqueous solutions of lead salts; lead ions were taken up by the algae mainly by sorption onto the particles of organic matter. A wastewater treatment method, based on the removal of heavy metals including lead, by algae, is used in the Missouri Lead Belt (Wixson and Jennett, 1975), The term "heavy metal" is often used to designate elements of specific gravity higher than about 4, especially those which are regarded as possibly toxic under some conditions.

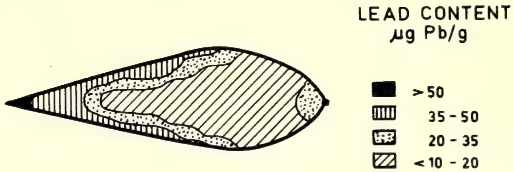


Fig. 2. Distribution of lead in a eucalyptus leaf

In general, most lead in soils is unavailable to plants. However, there is always some lead present in plants, the amounts depending on several factors mentioned before. It is not easy to estimate a value for what could be regarded as normal plants, but most values would be in the range 0.1-10 ppm in dry matter. Most normal trees, shrubs and grasses have 10-100 ppm Pb in ash, but lichens and mosses may have up to 1000 ppm Pb in ash. Cannon (1976) has reviewed several aspects of lead in vegetation.

LEAD IN NATURAL WATERS

A proper discussion of lead in natural waters should include lead in bottom sediments and particulate matter, because the level of lead in solution depends on equilibria between these solids and water. The concentration of lead in water is also governed to a large extent by the insolubility of lead compounds, such as carbonate, sulphate, sulphide and phosphate. In terms of these compounds, the solubility of lead in dilute aqueous solution should not exceed 10 µg Pb/ℓ at ordinary temperatures, a pH of 7.6 to 12.6 and a bicarbonate concentration of more than 60 mg/ℓ (Hem, 1976). Increased solubility occurs under acid conditions, and in very saline waters, where lead chlorocomplexes could be formed. Hence, in general, the release of lead during weathering tends to be a slow process.

In a river, lead may be present in various forms, namely (a) in solution, (b) in particulates, (c) associated with organic matter, and (d) in living matter. Lead ions are not present in water as free entities; lead in solution is probably partly as simple inorganic hydrated ions and perhaps complexes with inorganic and organic matter. The alkalinity of water is an important factor in the complexing of lead. Particulates may contain inherent lead in their crystal structure, for example, lead in feldspar replacing some of the potassium, as well as surface-adsorbed lead on clays and on iron and manganese oxides. There is insufficient evidence on the nature of organic matter in water to more than conjecture that some complexes of lead with organic matter may be insoluble. Nissenbaum and Swaine (1976) found up to 600 ppm Pb (on a dry-weight basis) in humic material from

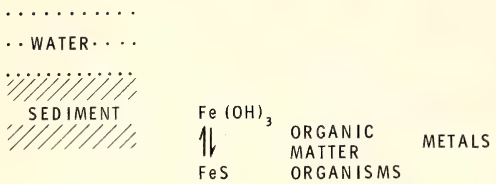


Fig. 3. The sediment-water interface

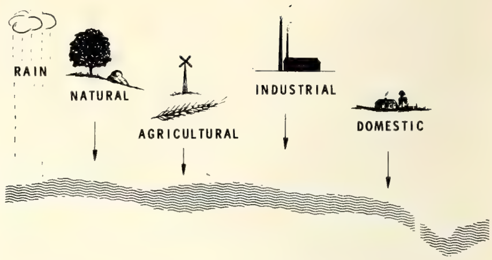


Fig. 4. Sources of lead in a river

marine reducing environments; variations in concentrations are possibly related to changes in the ability of the organic matter to fix lead due to changes in the nature of the organic matter at different stages of diagenesis. Living matter, plant and animal, contains some lead which is eventually returned to the bottom sediments.

Lake-bottom sediments normally contain lead at the several parts per million level, higher values being associated with drainage from a mineralised area. Gorham and Swaine (1965) found 200-800 ppm Pb (on a dry-weight basis) in reduced muds from Windermere and Esthwaite Water in the English Lake District. Some oxidate crusts from bottom sediments in the same lakes had up to 8000 ppm Pb, probably because of drainage from areas where there had been lead mines for several centuries. These samples were mostly high in iron and manganese, and iron and manganese oxides as concretions or thin layers on other particles are known to scavenge metals, including lead, from water.

In rivers and lakes, reactions at the sediment-water interface are important in the recycling of trace elements. The situation is shown in Fig. 3. In the sediment just below the interface, there is intense activity and change. Organic matter, comprising dead plant and animal debris, is being degraded biologically and microbiologically thereby depleting the oxygen level, producing carbon dioxide and in some cases lowering the pH. The resulting reducing conditions will favour the mobilisation of lead which can then be returned to the overlying water layer by movement of the interstitial water in the sediment. Such movement may be caused by burrowing organisms and by fish stirring the surface layers of the sediment. At the same time the particles are aerated before falling back into the sediment. The whole process continues until there is no organic matter left for degradation, thereby limiting the oxygen-consuming reactions, lessening the evolution of carbon dioxide and stabilising the pH. At this stage, compaction of the sediment under the hydrostatic pressure can take place. During the above changes in oxidation-reduction potential, hydrated iron oxides formed during the oxidation stage will adsorb some lead, but this will be desorbed during the reduction stage, when an iron sulphide (FeS) forms from bisulphide ions and hydrogen sulphide. The breakdown of the organic matter and the reduction of sulphate enables lead and other metals to form insoluble sulphides, including galena. Heavy metals are probably finally fixed in most sediments as sulphides. As well as postulating what may be happening during the early stages of sedimentation, the above sequence of reactions may explain how a sediment is consolidated. In other words, the main controlling factor is the biological or microbiological oxidation of organic matter.

There is laboratory evidence for the formation of tetramethyl lead, $(CH_3)_4Pb$, by the action of certain micro-organisms on samples of some sediments (Wong *et al.*, 1975), the conversion being entirely biological and probably being favoured by the higher oxidation state of lead ($Pb^{4+}$). As yet, the relevance of this to lead in sediments *in situ* has not been established.

It is interesting to postulate what happens to lead in rivers. The various possible sources of lead are shown in Fig. 4. Lead in the atmosphere comes from dust, volcanic gases, sea spray, forest fires, vegetation, smelters, brass manufacturing, coal combustion and the combustion of petrol containing lead-alkyls as additives, the latter being the main source. Hence, there is a constant addition of lead in rainfall, some ultimately reaching rivers. Weathering of rocks and soils and decomposition of vegetation and animal-matter will also provide small amounts of lead. Fertilisers, especially phosphate-types, and insecticides are probably the only agricultural sources of lead, albeit at trace levels. Industrial operations contribute some lead in effluents, while the main domestic sources are sewage and old paint. As pointed out already, lead is unlikely to remain in true solution for long, because of the insolubility of several inorganic compounds, the adsorption on particulate matter and possibly the formation of insoluble lead-organic matter complexes. Eventually, particles are deposited on the river bed. However, flooding may stir up some of these bottom sediments and move them along the river bed, perhaps changing conditions so that there is an increase in solubility, for example, a change to lower pH may eventuate from a change to still conditions where biological breakdown of organic matter can occur. Hence, the fate of lead in rivers is governed by factors which generally tend to keep the concentration of soluble lead low. It is important to realise that the system is a dynamic one, and to be aware of this before taking samples for analysis. The common practice of filtering water samples through a 0.45 μm filter before analysing the filtrate means that a measure is obtained of soluble lead, which includes some colloidal lead. At the same time, lead adsorbed on particulate matter

(clays, iron and manganese oxides, organic material) is not determined, although it may be important under other conditions in the same river.

LEAD IN COAL

Although coal (mean content about 10 ppm Pb) contains more lead than oil (less than 1 ppm Pb), the combustion of coal does not contribute as much lead to the atmosphere as the combustion of petrol, because petrol contains lead-rich additives. For example, in the U.S.A. in 1968, lead emissions from petrol combustion comprised 181,000 tonnes compared with 920 tonnes from coal combustion (Lovering, 1976). Research on Australian bituminous coals has given much information on lead and other trace elements (Brown and Swaine, 1964). The range of values for most New South Wales and Queensland bituminous coals is 2-40 ppm Pb, with a mean value of about 10 ppm in air-dried coal, some of the lead occurring as galena (PbS); most Victorian brown coals have less than 5 ppm Pb. This means that many coals have less lead than many shales (mean content of 20 ppm Pb). Values are sometimes given in terms of coal ash, the range for New South Wales and Queensland coals then being 20-200, with a mean of about 60 ppm Pb.

It has been estimated in the U.S.A. that up to 6 per cent of the total lead in coal may be released into the atmosphere during combustion (Lovering, 1976). During the combustion of coal in lump form on grates, using spreader-stoker or chain-grate methods, lead is set free and finally fixed in the slag, ash and in deposits on various parts of the boiler. Some deposits on superheater tubes show great enrichment in lead, one sample having 2 per cent Pb, which represents a two thousand-fold concentration from the coal. Some deposits show differences in composition between the inner layer next to the superheater tube (1 per cent Pb) and the outer layer (0.004 per cent Pb). Perhaps the lead is present as a lead phosphate, by analogy with boron phosphate ($BPO_4$) and boron arsenate ($BAsO_4$) in solid solution in boron phosphate which have been found in some deposits (Swaine and Taylor, 1970).

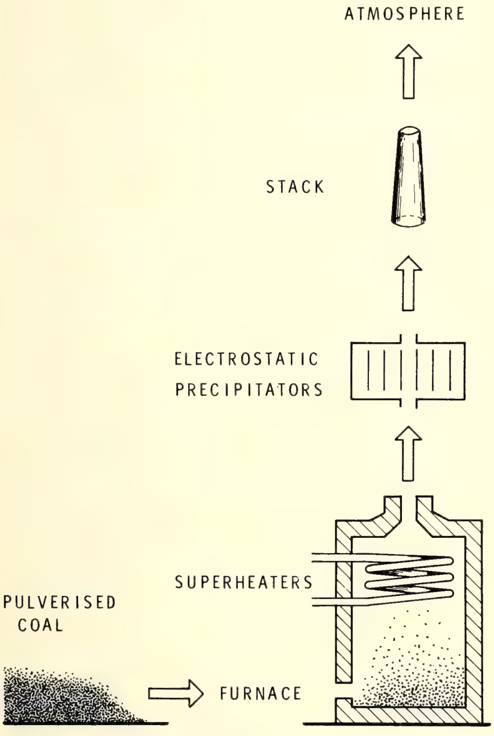


Fig. 5. Pictorial representation of a modern pulverised-coal-fired boiler

In the modern method of coal combustion for the generation of electricity, pulverised coal is fired under conditions yielding predominantly fly-ash. Fly-ash is the incombustible residue, mostly of micron and sub-micron size, which is formed from up to 90 per cent of the inorganic matter in the coal. Most of the fly-ash is retained by the electrostatic precipitators (Fig. 5), although small amounts reach the atmosphere with the stack gases. The fate of lead during combustion is shown diagrammatically in Fig. 6. Lead in coal particles and in galena and possibly that in feldspar and similar

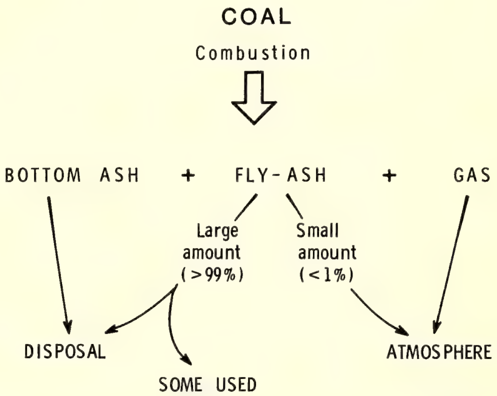


Fig. 6. The distribution of lead after combustion

minerals, is released at the temperatures of combustion (1600-1700°C). The bottom ash contains some lead, probably as a complex silicate, while fly-ash has a similar lead content to coal-ash. Swaine (1977) has postulated that lead is removed from the cooling flue gases and fixed on the surface of fly-ash particles, either by sorption or by reaction to form lead sulphate. Some lead may reach the atmosphere in very finely divided fly-ash. Hence, efficient electrostatic precipitation is an important restriction on the amount of lead emitted with the stack gases. Any lead reaching the atmosphere is dispersed widely, eventually being returned to the earth in rain. Fly-ash in rain will scarcely affect the levels of lead in soils, as fly-ash from Australian bituminous coals has 30-300 ppm Pb, which is similar to the lead content of most soils, 2-200 ppm Pb (Swaine, 1955). Although lead is dispersed widely in the atmosphere, varying in concentration at different places, no marked effect was found at Macquarie Island, South Pacific Ocean, where samples of peaty material had 2 ppm Pb and lead was not detected (less than 10 ppm Pb) in samples of morainic material and weathered rock (Swaine, 1957).

LEAD IN FERTILISERS

Cultivated soils may gain some lead from certain insecticides, but the amounts from fertilisers rarely affect plants. Most potassium and nitrogen fertilisers have less than 1 ppm Pb, calcium fertilisers less than 10 ppm Pb and phosphorus fertilisers up to about 100 ppm Pb (Swaine, 1962). A simple calculation will show the negligible effect of lead added to soil in a fertiliser. The addition of 100 kg per hectare per year of a fertiliser containing 100 ppm Pb increases the concentration of lead in the surface 20 cm of soil by a mere 0.01 ppm Pb. Sewage sludge is sometimes added to soils as a fertiliser, and this may increase the contents of some trace elements in plants after repeated additions of sludge. However, no trouble has been reported for lead, which is present in sewage sludges in the range of 120-3000 with a mean of 700 ppm Pb in dry material (Swaine, 1962; Berrow and Webber, 1972).

SOURCES OF LEAD IN THE BODY

The foregoing discussion of the geochemistry of lead has indicated the widespread occurrence of lead, hence it is not surprising that the body may derive lead from several sources, summarised in Fig. 7. Some lead reaches the body in food, water and air. Food derives lead from plants and animals

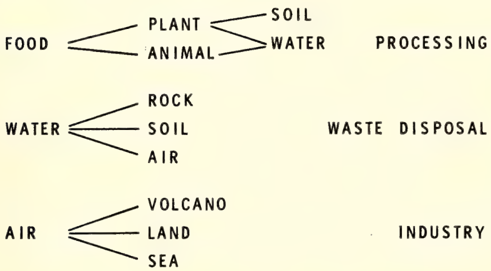


Fig. 7. Sources of lead in the body

and possibly from processing, but the levels are not high, except perhaps for some vegetation adjacent to busy highways. Water acquires very small amounts of lead from rocks, rain and possibly from waste disposal in certain areas. The treatment of water to purify it for drinking purposes removes most of the lead. As well as input from some industries and from petrol, the air receives some lead from volcanoes, wind-borne dust and sea-spray. In general, there is an awareness of the need to restrict unwarranted emissions of lead into the environment. The toxic effects of exposure to undue amounts of lead are known, and precautions are taken to protect workers in industries where there could be occupational health problems. It should be remembered that the body has always been exposed to some lead; the intake of a so-called "normal" person is said to be 300-500 μg Pb per day. Some lead is retained, mostly in the bones. There are some local sources of lead that may be troublesome. For example, the use of lead pipes for domestic water supplies may give some soluble lead if the water is of low hardness. Ceramic ware with lead glazes and cigarettes are other sources of lead for some people. Lead poisoning may come from the ingestion of flakes of lead-based paint by children, especially in old houses. The level of lead in paint in Australia is controlled by law to prevent toxic effects.

In certain countries there is legislation to reduce the amount of alkyl-lead additives in petrol, but this is not a simple matter, as leaded petrol has advantages over other petrol. The production of lead-free petrol of high-octane value, which is necessary for high-efficiency engines, uses more crude oil and increases costs. A more realistic approach would seem to be the reduction of lead in exhaust gases by means of a filter, thereby attaining conservation of oil and a reduction in atmospheric lead, as well as retaining the desirable properties of a leaded petrol. If particulate lead from the combustion of petrol is easily absorbed by the body, then there would seem to be a case for lowering the lead content of petrol, consistent with efficiency and economy.

CONCLUDING REMARKS

Pollution should be regarded as something imposed on a natural background. For example, in the case of lead, a consideration of the geochemical cycle, as outlined above, gives a perspective which should prevent a hasty judgement on possible untoward effects of lead. Unfortunately, there are gaps in the quantitative understanding of geochemical cycles, including that of lead. This limits the impact of geochemistry on the assessment of some practical pollution problems. Current research is closing many of these gaps and there is now a realisation of the importance of geochemistry in environmental science. Good data are a prime need. In this connexion, the statement by I.P. Pavlov in his "Letter to Youth" is pertinent:

> "No matter how perfect a bird's wing may be, it could never lift the bird to any height without the support of air. Facts are the air of science"

A proper consideration of pollution on the local and on the global scale depends on a sound knowledge of geochemical cycles and of natural background levels, always remembering that we are dealing with dynamic systems, where biological factors are often dominant.

As well as many uses in industry, several metals, for example copper and zinc, are necessary in life processes. They have a dual role, namely, essentiality (usually in very small amount) and possible toxicity. Sometimes there is a narrow boundary between what is regarded as essential and what may be toxic. There are rarely doubts about acute toxicity, namely, that brought about by a relatively large dose, but it is difficult to establish what are the conditions for chronic toxicity, namely that arising from the ingestion of small amounts over a long period of time. Brown (1976, page 63) has stated that "it should be recognised that all living things are in one sense "accumulations" of chemicals and it is only when substances, such as heavy metals, are absorbed at rates faster than those at which they can be excreted, and which are more or less constantly in the environment at levels significantly above "natural" levels, that they are likely to exceed

tolerable levels in the tissues and be harmful". In a review of a recent conference, Freedman (1977) has included "possibly lead" in a list of trace elements essential for mammals. Kothny (1973) has warned against condemning "trace elements with apparently no value" before the metabolic process is properly understood. It is salutary to recall that the essentiality of selenium and chromium for animal life has been established in the last decade (Underwood, 1977). However, the requirements of such elements are usually very low, and it is clear that if lead is shown to be essential, then only small amounts would be required.

Let me conclude with a plea for careful scientific consideration of matters concerning trace elements in the environment where pollution or possible toxic effects are in question. Perhaps a proper perspective and degree of common sense can be summed up in a pseudo-chemical equation, namely

$$\mathbf{C} \rightleftharpoons \mathbf{D}$$

**Conservation** **Development**

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CSIRO Fuel Geoscience Unit,
NORTH RYDE, N.S.W. 2113.



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# Report of Council for the Year Ended 31st March, 1978

Presented at the 111th Annual General Meeting of the Society held on 5th April, 1978.

INTRODUCTION

The year has seen the settling-in of the Society in the Science Centre. The office arrangements have worked smoothly and effectively and the financial situation, whilst still of concern to Council, shows the benefits arising from the economies put in train the previous year.

Sir John Kerr requested that he be permitted to retire from the office of Patron of the Society upon relinquishing his appointment as Governor General of Australia, and Council acknowledges with appreciation the support Sir John had given to the Society by his patronage.

Council has much pleasure in announcing that His Excellency, Sir Zelman Cowen, A.K., G.C.M.G., K.St.J., Q.C., Governor General of Australia, has graciously granted his patronage to the Society.

MEETINGS

Council held 11 meetings during the year and dealt with all the business matters of the Society. Attendance of members of Council at these meetings ranged from 13 to 17.

Nine general monthly meetings were held during the year, together with two special meetings, namely "The Clarke Memorial Lecture and "An Evening at the Macleay Museum". Abstracts of these meetings will be published in the Journal and Proceedings; abstracts of the lectures have already been published in the Society's Newsletter. Average attendance at the general monthly meetings was 40. Council considers this figure to be disappointingly low considering the excellent standard of the lectures and urges members of the Society to take advantage of the opportunities that these lectures provide, of becoming better informed on a wide variety of interesting topics.

Council expresses its sincere thanks to all the speakers who contributed to a thoroughly interesting series of lectures.

ANNUAL DINNER

The Annual Dinner was held in the Sydney Hilton Hotel on 17 March 1978 and was attended by 90 members and guests. The guest speaker was Sir Asher Joel, K.B.E., M.L.C., F.R.S.A., the title of his address being "The Political Permutations of Housey-Housey".

AWARDS

The following awards for 1977 were made:-

| | |
|---|---|
| James Cook Medal | Emeritus Professor Irvine A. Watson |
| Edgeworth David Medal | Professor R.A. Antonia |
| Clarke Medal | Dr. A.F. Trendall |
| The Society's Medal | Mr. J.W. Humphries |
| Walter Burfitt Medal & Prize | Dr. Allen Kerr |
| Clarke Memorial Lectureship | Professor J.F.G. Wilkinson |

SUMMER SCHOOLS

The two Summer Schools held during January for fifth form Secondary students again proved successful with a total of 52 students attending. The Chemistry School, "Chemistry and the Swimming Pool", was held in conjunction with Macquarie University as in previous years. The second school was in the field of Geology with the theme title "Man, Mining and the Environment".

Council expresses its sincere thanks to all who contributed to make these schools a success.

MEMBERSHIP

The membership at 31 March 1978 was:

| | |
|---|---|
| Honorary Members | 12 |
| Life Members | 37 |
| Members | 339 |
| Associate Members | 50 |
| Company Member | 1 |

Professor Sir John Cornforth was elected to Honorary Membership in 1977.

PUBLICATIONS

Volume 110 of the Journal and Proceedings was published during the year.

There were also nine issues of the Society's monthly Newsletter. This continues to be a successful medium for communicating information on Society activities to members and the special feature articles are of particular interest. The assistance of Dr. J. Dulhunty in collecting and editing these feature articles is gratefully acknowledged.

LIBRARY

The Library has continued to meet the demands made upon it and 143 requests for material were received; of these, 94% were from Commonwealth and State Departments, Universities, Colleges, Companies, Hospitals and similar organizations, and only 6% from members of the Society.

Some 2,321 items were received and processed; these comprised periodicals on exchange from 368 societies and institutions in addition to donations and purchases. The library has continued to be open only two full days per week and Librarian, Mrs. G. Proctor, has maintained the library services at a high level.

FINANCE

The accompanying financial statements show that a deficit of $420 was incurred on operations during the year. This amount was affected by the abnormal circumstance that the Government subsidies for both 1976 and 1977 were received during 1977. If the subsidy attributable to 1976 is credited to the deficit for that year the 1976 deficit becomes $9271 and the deficit for 1977 becomes $2920. The improvement is considerable and is largely due to a strenuous effort to contain costs. The interest received from general investments was sharply reduced due to the need to draw on invested capital

to finance the deficits of 1976 and 1977.

At the close of the year the Society received its share of the estate of the late Dr. J.F. Codrington, whose will (in 1940) had nominated the Society as a joint beneficiary, subject to life-time legacies. The sum will be invested to provide income to assist in maintaining the Society's operations. Unless unforeseen circumstances arise, it should thus be possible to avoid a deficit in the coming year and the assistance in achieving this aim provided by Dr. Codrongton's generous bequest is gratefully acknowledged.

The provision for longservice leave liability was discontinued by Council because the Society has no present liability nor will it have in the foreseeable future. Further, the Council resolved to capitalize a substantial part of the accumulated revenue of the trust funds since there had been no previous action to sustain their capital value despite the ravages of inflation. The change will increase the interest revenue of each fund and thereby facilitate the proper execution of the donor's wishes.

Members and friends of the Society are reminded that maintenance of the Library costs the Society in the vicinity of $5000 per annum, excluding floor rental. Attempts to gain direct Government assistance with the costs associated with this nationally important collection have all so far failed. However, all donations of $2.00 or more to the "Royal Society of New South Wales Library Fund" are tax deductible and will be appreciated.

SCIENCE CENTRE

The Science Centre has made significant progress during the year. It now provides secretarial facilities to some 16 kindred organizations and its conference and lecture room facilities are steadily becoming more and more used.

The financial situation of the Science Centre however, continues to be grave. The Fund Raising Appeal has so far failed to attract sufficient donations to make any realistic impact on the overall indebtedness to the Commonwealth Bank. This situation is of very real concern to your Council and to your four Directors on the Board of the Centre and a number of avenues are being explored which may lead to an improvement.

Your Council continues to believe that the concept of the Science Centre is inherently sound and is determined to do its utmost to ensure that that concept shall be carried forward successfully and that the future of this Society shall be ensured.

ACKNOWLEDGEMENTS

Council once again acknowledges the excellent work of Mrs. Judith Day in the general running of the Society' office and of Mrs. Grace Proctor in the running of the Society's Library. Council also wishes to record its appreciation to all those who contributed to the organization of, and the success of, the various activities of the Society during the year.

ANNUAL REPORT OF THE NEW ENGLAND BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

OFFICERS

Chairman: S.C. Haydon
Secretary Treasurer: R.E. Gould
Committee: R.L. Stanton, N.T.M. Yeates (resigned during year), R.D.H. Fayle, N.H. Fletcher.
Representative on Council: R.L. Stanton

MEETINGS

The following meetings were held:

| | |
|---|---|
| 21 June 1977 | "Reconstructing Triassic Vegetation of Eastern Australia", Mr. G.J. Retallack, Geology Department, University of New England. |
| 13 August, 1977 | "Coal, Sugar Cane and Uranium; energy policy options for Australia", Dr. I. Lowe, The Open University, London, England. |
| 8 September, 1977 | "Environmental Pollution by Heavy Metals - their effects on human and animal health", Prof. H. Bloom, Professor of Physical Chemistry, University of Tasmania. |
| 16 September, 1977 | "The Witwatersland Goldfield - changing ideas", Prof. D. Pretorius, Professor of Economic Geology, University of Witwatersland. |

FINANCIAL STATEMENT

| | | |
|---|---|---|
| Balance as at 31 December 1976 | $204.50 | |
| Credit - Interest to 29 June 1977 | 3.57 | |
| - Royal Society of N.S.W.- Council Grant | 100.00 | |
| - Interest to 29 Dec. 1977 | 4.14 | |
| | | $312.21 |
| Debit - Advertising | $ 5.60 | |
| - Miscellaneous | 5.67 | |
| | | $ 11.27 |
| Balance as at 31 December 1977 | | $300.94 |

ANNUAL REPORT OF THE SOUTH COAST BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

OFFICERS

Chairman: B.E. Clancy
Secretary Treasurer: G. Doherty
Representative on Council: G. Doherty

No meetings of the Branch were held during 1977.

FINANCIAL STATEMENT

| | | |
|---|---|---|
| Balance as at 31 December 1976 | $ 48.25 | |
| Credit - Interest to 24 June 1977 | 0.78 | |
| | | $ 49.03 |
| Balance as at 31 December 1977 | | $ 49.03 |

CITATIONS

## EDGEWORTH DAVID MEDAL

The Edgeworth David Medal for 1977 is awarded to Professor Robert Anthony Antonia for distinguished contributions to engineering research. This award is restricted to scientists under the age of 35.

Professor Robert Anthony Antonia holds the Chair of Mechanical Engineering, University of Newcastle, New South Wales. Aged 34, Professor Antonia already has an established international reputation. His research has been primarily in the field of fluid flow, with particular reference to turbulance. He has published 67 papers, all but one of which are based on work carried out in Australia.

Professor Antonia graduated B.E. (Sydney) in 1964 and obtained his Ph.D. (Sydney) in 1970. In 1972 he was appointed Lecturer in Mechanical Engineering and in 1975, Senior Lecturer within the University of Sydney. He was appointed to the Chair at Newcastle in January 1976.

In awarding the Edgeworth David Medal to Professor Antonia, the Royal Society of New South Wales recognizes in him one of Australia's most brilliant young scientists. His achievements to date have been outstanding.

## THE JAMES COOK MEDAL

The James Cook Medal for 1977, for outstanding contributions to Science and Human Welfare in and for the Southern Hemisphere, is awarded to Emeritus Professor Irvine Armstrong Watson.

Professor Watson retired from the University of Sydney in 1977 being at that time the first Director of the Institute of Plant Breeding and Head of the Department of Agricultural Botany. During his distinguished career of some 39 years at the University of Sydney he made important, and internationally acclaimed, contributions to knowledge of the genetics of the interaction of the wheat plant and wheat rust fungi. Additionally he made significant contributions to agriculture by the development of new wheat varieties of high quality and rust resistance.

Professor Watson's early research was concerned with the genetics of virulence in wheat rust organisms and the genetical nature of the resistance to them in the wheat plant. He showed that when specific resistance in the host was considered, a number of loci could be established in the host which controlled this resistance. This laid the groundwork for the broad genetic approach to breeding rust resistant wheats. Professor Watson developed the concept of the negative relationship between genes for virulence on the one hand and genes for fitness on the other. He also carried out very significant work on the nature of asexual variation in the wheat stem rust organism, and the techniques he developed have been followed by other workers to demonstrate the same processes in other organisms.

The work on breeding of new rust resistant varieties of wheat was given significant impetus in the 1950's when cytogenetical studies were begun to determine the feasibility of combining genes. The success of this work is evidenced by the now extensive cultivation of new wheats in which several genes have been combined; in the traditional rust areas of northern N.S.W. and Queensland there have been no significant losses from rust in 25 years, although, during the same period, major losses have been recorded on three separate occasions in other parts of N.S.W. Rust resistance has been combined with improved and stabilized yields. Over one third of Australia's wheat area is now planted with these new wheats.

Professor Watson has published widely and has received recognition as a leading authority in wheat breeding, not only nationally but internationally; he has received a number of distinguished awards including election as a Foreign Member of the Soviet Academy of Agricultural Sciences (1972).

Professor Watson is indeed a worthy recipient of the James Cook Medal.

## THE CLARKE MEDAL

The Clarke Medal for 1977 for distinguished work in the natural sciences is awarded to Dr. Alec Francis Trendall.

After graduating from Imperial College, London, and from Liverpool University, Dr. Trendall spent some time as a geologist with South Georgia Survey and with the Geological Survey of Uganda. In 1962 he joined the Geological Survey of Western Australia where he is currently Deputy Director.

Following some sound work on the Precambrian basement in Uganda, Dr. Trendall carried out an original study on laterite and erosion surfaces. However, his main research has been on the banded iron-formations of the Hamersley Basin, where his detailed stratigraphic and petrographic work has led to significant

advances, recognized internationally and summarized in his paper on "Three great basins of Precambrian banded iron formation deposition: a systematic comparison." The ramifications of this work are given in his paper "Revolution in earth history," published in 1972. His current research, including geochronological studies with J.R. de Laeter, is helping to elucidate the Precambrian of Western Australia.

Dr. Trendall is very active professionally. He has been President of the Geological Society of Australia and of the Royal Society of Western Australia. He is currently a member of the Australian National Committee for Geological Sciences of the Australian Academy of Science, and has served as a member of the Australian National Committee for the Upper Mantle Project and International Geological Correlation Programme (I.G.C.P.).

It is fitting that a geologist of the scientific and professional standing of Dr. Alec Trendall should receive the one hundredth award of the Clarke Medal.

## THE SOCIETY'S MEDAL

The Society's Medal for 1977 is awarded to Mr. J.W. Humphries for his work on precision measurements in physical metrology, and particularly for his contribution and service to the Society.

Mr. Humphries is a New Zealander and it was in his capacity as an officer of the New Zealand D.S.I.R. that he was first involved with precision measurements and, during the war years, with maritime navigational equipment.

Coming to Australia to join the C.S.I.R.O. National Measurement Laboratory he has continued his work on precision measurement, and he has had the responsibility for the custodianship and maintenance of the Australian National Standard of Mass, this has resulted in him being involved in work where precision and accuracy of one part in one hundred million is the requirement.

Mr. Humphries joined the Society in 1959 and has served for many years on Council, being President in 1964. He has been an office bearer and has served on most of the Society's Sub-committees, and was Honorary Secretary from 1972 - 1976. In addition Mr. Humphries represents the Society as a Director on the Board of Science House Pty. Limited.

Many new members and visitors have been grateful to Jack Humphries for his ability to make them feel so much at ease and welcome at our meetings; this ability together with his willingness to serve our Society in so many different ways indeed makes him a very worthy recipient for the Society's Medal.

## WALTER BURFITT PRIZE

The Walter Burfitt Prize for 1977 is awarded to Dr. Allen Kerr of the Waite Agricultural Research Institute, Adelaide, for his work on biological control of crown gall in stone fruit trees. This is the first time the award has been made in the field of agriculture.

The Walter Burfitt Prize is awarded at intervals of three years for original work of the highest scientific merit in pure or applied science, carried out in Australia or New Zealand, by a worker resident in one of these countries.

Dr. Kerr's work on biological control of crown gall is unique and the scientific and economic implications of his discovery are far-reaching. Dr. Kerr's basic finding, described in an article in *New Scientist* as "almost too good to be true", is that by treating seedlings with a non-virulent strain of the causative agent, not giving rise to any disease symptoms, trees are enabled to grow healthily, even in soils infected by the disease-producing bacterium.

Dr. Kerr has successfully integrated several lines of research to provide the first really useful means of controlling crown gall of stone fruit, and to provide a brilliant theoretical analysis of the inhibition of the pathogenic agrobacteria by a non-pathogenic, antibiotic-producing strain. The rapid acceptance of Dr. Kerr's non-polluting biological control technique by overseas scientists is a measure of the trust placed in his work.

# Financial Statements for 1977

AUDITORS REPORT TO THE MEMBERS

In our opinion:

(a) the attached balance sheet and income and expenditure account are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1977 and of the results of the Society for the year ended on at date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provision of those Rules.

WYLIE & PUTTOCK
Chartered Accountants.

By ALAN M. PUTTOCK
Registered under the Public Accountants Registration Act, 1945 as amended.

BALANCE SHEET as at 31/12/77

| | | | | |
|---|---|---|---|---|
| | RESERVES | | | |
| 7,200 | Library Reserve (note 2(i)) | | | 7,200 |
| 416,991 | Resumption Reserve (note 2(ii)) | | | 416,991 |
| 93,822 | LIBRARY FUND (note 2(iii)) | | | 2,220 |
| 806 | LONG SERVICE LEAVE FUND | | | - |
| 11,374 | TRUST FUNDS (note 4) | | | 11,919 |
| 35,742 | ACCUMULATED FUNDS | | | 76,829 |
| 565,935 | TOTAL RESERVES & FUNDS | | | 515,159 |
| | CURRENT ASSETS | | | |
| 187 | Petty Cash Imprest | | 61 | |
| 1,075 | Debtors for Subscriptions | 1,605 | | |
| 1,075 | Less Provision For Doubtful Debts | 1,605 | - | |
| 1,865 | Other Debtors & Prepayments | | 2,295 | |
| 7,426 | Interest Bearing Deposit | | 8,020 | |
| 10,420 | Cash at Bank | | 3,295 | |
| 19,898 | | | | 13,671 |
| | Less: CURRENT LIABILITIES | | | |
| 13,683 | Sundry Creditors & Accruals | | 5,023 | |
| 4 | Life Members Subscriptions - Current Portion | | 6 | |
| 40 | Membership Subscriptions Paid in Advance | | 68 | |
| 1,362 | Subcriptions to Journal Paid in Advance | | 1,366 | |
| 15,089 | | | | 6,463 |
| 4,809 | NET CURRENT ASSETS | | | 7,208 |

| | | | |
|---|---|---|---|
| | Add: FIXED ASSETS | | |
| 7,888 | Furniture, Office Equipment, etc.- at cost less Depreciation | 7,840 | |
| 2 | Lantern - at cost less Depreciation | 2 | |
| 13,600 | Library - 1936 Valuation | 13,600 | |
| 13 | Pictures - at cost less Depreciation | 12 | |
| 21,503 | | | 21,454 |
| 26,312 | | | 28,662 |
| | Add: INVESTMENTS | | |
| 27,180 | Commonwealth Bonds & Inscribed Stock | 26,580 | |
| - | Interest Bearing Deposits | 40,000 | |
| 27,180 | | | 66,580 |
| | Add: ASSOCIATED CORPORATIONS (note 3) | | |
| 1 | Shares - at Cost | 1 | |
| 512,495 | Advances & Loans - Unsecured | 419,995 | |
| 512,496 | | | 419,996 |
| 565,988 | | | 515,238 |
| | Less: NON-CURRENT LIABILITIES | | |
| 53 | Life Members Subscriptions - Non-Current Portion | | 79 |
| 565,935 | NET ASSETS | | 515,159 |

W. H. ROBERTSON Honorary President

A. A. DAY Honorary Treasurer

## STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31 December 1977

| | | | |
|---|---|---|---|
| 11,771 | DEFICIT for year | | 420 |
| 1,303 | Donations & Interest to Library Fund | | 4,793 |
| - | Proceeds Estate Late Dr. J. F. Codrington | | 37,504 |
| 1,840 | Transfer from Library Reserve | | - |
| 278 | Transfer from Library Fund | | 96,395 |
| 7,573 | Transfer from Resumption Reserve | | - |
| - | Transfer from Long Service Leave Fund | | 806 |
| 37,822 | Accumulated Funds-Beginning of Year | | 35,742 |
| (37,045) | AVAILABLE FOR APPROPRIATION | | (174,820) |
| 1,303 | Transfer to Library Fund | 4,793 | |
| - | Payment for Provision of Library Facilities | 93,198 | |
| 1,303 | | | 97,991 |
| 35,742 | ACCUMULATED FUNDS-Current Year | | 76,829 |

NOTES TO AND FORMING PART OF THE ACCOUNTS
for the year ended 31st December, 1977

### 1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1977. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

| | |
|---|---|
| Furniture | 7.5% |
| Office Equipment | 15.0% |

(b) Deficit from Operations

The balance of the Resumption Reserve, after lending $416,990 to Science House Pty. Ltd., has been fully allocated to meet operating deficits. (see also notes 2(ii) and 3)

### 2. MOVEMENTS IN PROVISIONS AND RESERVES

(i) Library Reserve

| | 1976 $ | 1977 $ |
|---|---|---|
| Balance at 1st January 1977 | 9040 | 7200 |
| Less Transferred to accumulated funds re: Library recataloguing | 1840 | - |
| Balance at 31st December 1977 | $7200 | $7200 |

(ii) Resumption Reserve

| | 1976 $ | 1977 $ |
|---|---|---|
| Balance at 1st January 1977 | 424564 | 416991 |
| Less Transferred to accumulated funds re: Operating deficit current year | 7573 | - |
| Balance at 31st December 1977 | $416991 | $416991 |
| Represented by: | | |
| Shares in associated corporation | 1 | 1 |
| Loans to associated corporation | 416990 | 416990 |
| | $416991 | $416991 |

(iii) Library Fund

| | 1976 $ | 1976 $ | 1977 $ | 1977 $ |
|---|---|---|---|---|
| Balance at 1st January 1977 | | 92797 | | 93822 |
| Add Donations and bank interest | | 1303 | | 4793 |
| | | 94100 | | 98615 |
| Less Library purchases | 278 | | 150 | |
| Library fittings | - | | 2547 | |
| Paid re library facilities | - | | 93198 | |
| Advance to general funds re preparation of subject index | - | | 500 | |
| | | 278 | | 96395 |
| Balance at 31st December 1977 | | $93822 | | $2220 |
| Represented by: | | | | |
| Cash at bank | | 22 | | 1049 |
| Loans to associated corporation | | 92500 | | - |
| Commonwealth Bonds | | 1300 | | 1300 |
| Owing to general funds | | - | | (129) |
| | | $93822 | | $2220 |

### 3. ASSOCIATED CORPORATIONS

The Society has entered into a joint venture with the Linnean Society for the establishment of a Science Centre for New South Wales and to facilitate this, a company, Science House Pty. Limited, has been formed in which each Society has 50% interest.
Advances and loans to the company have been on an interest free basis repayable at call. No material repayments are anticipated prior to 31st December, 1978

| | 1976 $ | 1977 $ |
|---|---|---|
| Total amount advanced | 512495 | 512495 |
| Less | | |
| Repaid during year | - | 92500 |
| Balance at 31st December 1977 | $512495 | $419995 |
| Representing: | | |
| Resumption reserve | 416990 | 416990 |
| Library fund | 92500 | - |
| Accumulated funds | 3005 | 3005 |
| | $512495 | $419995 |

### 4. TRUST FUNDS

| | 1976 $ | Clarke Memorial $ | Walter Burfitt Prize $ | Liversidge Bequest $ | Olle Bequest $ | Total $ |
|---|---|---|---|---|---|---|
| **Capital** | | | | | | |
| Balance at 1st January 1977 | 7000 | 3600 | 2000 | 1400 | - | 7000 |
| Capitalisation of accumulated revenue | - | 1200 | 1000 | 600 | 1300 | 4100 |
| Balance at 31st December 1977 | $7000 | $4800 | $3000 | $2000 | $1300 | $11100 |
| **Revenue** | | | | | | |
| Revenue income for period | 772 | 464 | 290 | 193 | 247 | 1194 |
| Less Expenditure | 50 | 555 | 27 | - | 67 | 649 |
| | 722 | (91) | 263 | 193 | 180 | 545 |
| Add Balance from 1976 | 3652 | 1291 | 1099 | 629 | 1355 | 4374 |
| | 4374 | 1200 | 1362 | 822 | 1535 | 4919 |
| Less Capitalisation | - | 1200 | 1000 | 600 | 1300 | 4100 |
| Total Revenue | $4374 | $NIL | $362 | $222 | $235 | $819 |
| Total Trust Funds | $11374 | $4800 | $3362 | $2222 | $1535 | $11919 |

### FUNDS STATEMENT FOR THE YEAR ENDED 31ST DECEMBER 1977

| | 1976 $ | 1976 $ | 1977 $ | 1977 $ |
|---|---|---|---|---|
| **SOURCE OF FUNDS** | | | | |
| Operating deficit for the year | - | | (420) | |
| Add: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | - | | 708 | |
| Provision for doubtful debts | - | | 1174 | |
| Funds derived from operations | | - | | 1462 |
| Donations and interest to library fund | | 1303 | | 4793 |
| Withdrawal of investments | | 9900 | | 600 |
| Trust fund income | | 772 | | 1194 |
| Reduction in working funds | | 7607 | | - |
| Life membership subscriptions | | - | | 34 |
| Loan to associated company repaid | | - | | 92500 |
| Proceeds Estate Late Dr. J. F. Codrington | | - | | 37504 |
| | | $19582 | | $138087 |
| **APPLICATION OF FUNDS** | | | | |
| Operating deficit for the year | 11771 | | - | |
| Less: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | 252 | | - | |
| Provision for doubtful debts | 1014 | | - | |
| Funds applied to operations | | 10505 | | - |
| Loan to associated company | | 3005 | | - |
| Purchase of furniture & equipment | | 6017 | | 659 |
| Reclassification of life members subscriptions in advance | | 5 | | 8 |
| Increase in investments | | - | | 40000 |
| Trust fund expenses | | 50 | | 649 |
| Payment for provision of library facilities | | - | | 93198 |
| Increase in working funds | | - | | 3573 |
| | | $19582 | | $138087 |

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31 December 1977

| | | | | |
|---|---|---|---|---|
| | INCOME | | | |
| 7,298 | Membership Subscriptions - Ordinary | | | 7,286 |
| 5 | Membership Subscriptions - Life Members | | | 6 |
| 27 | Application Fees | | | 48 |
| 7,330 | | | | 7,340 |
| 2,923 | Subscriptions to Journal | | | 3,099 |
| - | Government Subsidy | | | 5,500 |
| 117 | Donations - Printing Journal & Publications | | | - |
| 10,370 | Total Membership & Journal Income | | | 15,939 |
| 4,152 | Interest Received | | | 2,656 |
| 567 | Sale of Reprints | | | 2,020 |
| 60 | Sale of Back Numbers | | | 1,019 |
| 343 | Sale of Other Publications | | | 192 |
| - | Donations - General | | | 2 |
| 27 | Annual Social Surplus | | | 59 |
| 739 | Summer School Surplus | | | 620 |
| - | Other Income | | | 714 |
| 16,258 | | | | 23,221 |
| | Less: EXPENSES | | | |
| 920 | Accountancy Fees | | 710 | |
| 48 | Advertising | | - | |
| 110 | Audit Fees | | 350 | |
| - | Branches of the Society | | 100 | |
| 136 | Cleaning | | 90 | |
| 252 | Depreciation | | 708 | |
| 131 | Electric Light & Power | | 425 | |
| 73 | Entertainment Expenses | | 131 | |
| 212 | Insurance | | 157 | |
| | Journal & Publication Costs | | | |
| 4,645 | Printing - Current Year Volume | 4,868 | | |
| 372 | Printing - Other Publications | - | | |
| 887 | Wrapping & Postage | 457 | | |
| | | | 5,325 | |
| - | Preparation of Index | | 395 | |
| 250 | Legal Costs | | - | |
| 599 | Library Purchases | | 747 | |
| 1,840 | Library Recataloguing | | - | |
| 1,967 | Library Relocation | | 1,638 | |
| 63 | Miscellaneous Expenses | | 61 | |
| 973 | Postage | | 1,197 | |
| 417 | Printing & Stationery - General | | 734 | |
| 1,014 | Provision for Doubtful Debts | | 1,174 | |
| 4,767 | Rent | | 2,458 | |
| 85 | Repairs & Maintenance | | 131 | |
| 6,946 | Salaries | | 5,914 | |
| 745 | Secretarial Services | | 883 | |
| 216 | Superannuation Contributions - Employees | | - | |
| 361 | Telephone | | 313 | |
| 28,029 | | | | 23,641 |
| 11,771 | DEFICIT for the year | | | 420 |

# Abstract of Proceedings, Year Ending 31st December, 1977

LOCATION

Science Centre, 35 Clarence Street, Sydney.

APRIL 6th

110th Annual General Meeting. The President, Dr. D.J. Swaine was in the chair and 63 members and visitors were present.

The Annual Report of Council and the Annual Statement of Accounts were adopted. Four papers were read by title only.

The Clarke Medal was awarded to Dr. Lilian Ross Fraser; the Edgeworth David Medal to Prof. R.H. Street (presented at September meeting); the Society's Medal to Mr. E.K. Chaffer and Archibald D. Olle Prize to Dr. L.A. Drake. Three prizes for essays based on the Summer School in Medicine (January 1977) were presented to Steven Harvey, Kathryn Byron and Estelita Ratanayagam.

Messrs. D.R. Wylie, Puttock and Kiely were elected Auditors.

The Presidential Address "Trace Elements in the Environment" was given by Dr. D.J. Swaine.

The incoming President, Mr. W.H. Robertson was installed and introduced to members.

MAY 4th

899th General Monthly Meeting. The President, Mr. W.H. Robertson was in the chair and 27 members and visitors were present. 4 new members were elected.

An address "The Fight against Metallic Corrosion" was given by Dr. E.C. Potter, Chief Research Scientist, C.S.I.R.O. Division of Process Technology.

JUNE 1st

900th General Monthly Meeting. Mr. E.K. Chaffer, Vice-President, was in the chair and 26 members and visitors were present. Council announced the admittance of 1 new associate member. 3 papers were read by title only.

An address "Some Problems in Urban Hydrology" was given by Dr. R.F. Warner, Department of Geography, University of Sydney.

JULY 6th

901st General Monthly Meeting. The President, Mr. W.H. Robertson was in the chair and 38 members and visitors were present. Council recorded with pleasure the award of O.B.E. to Mr. L.C. Noakes, Director of the Bureau of Mineral Resources, a member of the Society since 1945. 1 paper was read by title only.

An address "New Light on Early Man in East Africa" was given jointly by Dr. Martin Williams, School of Earth Sciences, and Dr. Don Adamson, School of Biological Sciences, Macquarie University.

AUGUST 3rd.

902nd General Monthly Meeting. The President, Mr. W.H. Robertson was in the chair and 23 members and visitors were present. 4 new members were elected and Council announced alterations to By-Law 4. 2 papers were read by title only.

An address "Non-medical uses of Neutron Activation Analysis" was given by Dr. C.J. Hardy, Program Manager Uranium Fuel Cycle, Australian Atomic Energy Commission.

SEPTEMBER 7th

903rd General Montly Meeting. The President, Mr. W.H. Robertson was in the chair and 52 members and visitors were present. 2 new members were elected and Council announced the admittance of 1 new associate member. 1 paper was read by title only. The Edgeworth David Medal was presented to Professor R.H. Street.

An address "Visual Illusions" was given by Mr. J. Alexander, School of Optometry, University of N.S.W.

OCTOBER 5th

904th General Monthly Meeting. The President, Mr. W.H. Robertson was in the chair and 56 members and visitors were present. 1 new member was elected and Council announced the admittance of 1 new associate member. 1 paper was read by title only.

An address "Old Ears and New Music" was given by Mr. F.R. Blanks, Organic Chemist, Author, Lecturer and Music Critic.

NOVEMBER 2nd

905th General Monthly Meeting. The President, Mr. W.H. Robertson was in the chair and 47 members and visitors were present. 1 new member was elected and Council announced the election to Honorary Membership of Prof. Sir John Cornforth, C.B.E., F.R.S.

A symposium was held with the theme "Oil and Australia's Future". The panel of speakers comprised Dr. G.H. Taylor, Chief Research Scientist, Mineral Research Laboratories, C.S.I.R.O.; Mr. F.S. Jeffries, Geological Co-ordinator, Esso Australia Ltd.; Mr. D.J. McGarry, Managing Director, Australian Oil and Gas Corporation Ltd.

DECEMBER 7th

906th General Monthly Meeting. The President, Mr. W.H. Robertson was in the chair and 30 members and visitors were present. 2 new members were elected.

An address "Nuclear Medicine - The Clinical Use of Radionuclides" was given by Prof. I.P.C. Murray, Director of Nuclear Medicine, Prince of

Wales Hospital, Sydney.

LOCATION

The Macleay Museum, University of Sydney.

MAY 18th

Members and guests attended a private viewing of the exhibition "The Mechanical Eye: A History of Photography." Mr. Alan Davies, a member of the Museum staff, gave a talk on the exhibition.

LOCATION

The Stephen Roberts Lecture Theatre, University of Sydney.

JULY 14th

The Clarke Memorial Lecture was given by Professor J.F.G. Wilkinson, Department of Geology, University of New England, the title of the address being "Petrogenetic Aspects of Some Alkali Volcanic Rocks."

MEMBERSHIP OF THE SOCIETY, APRIL 1978

During the year ended 31st March, 1978 the following changes in membership of the Society were effected.

ELECTION TO HONORARY MEMBERSHIP

CORNFORTH, Sir John, C.B.E., F.R.S., Royal Society Research Professor, University of Sussex, Brighton, Sussex, BN1 9Q5, England.

ELECTION TO LIFE MEMBERSHIP

McKERN, Howard Hamlet Gordon, M.Sc., A.S.T.C. (Chem.), F.R.A.C.I., 10 Beaconsfield Parade, Lindfield, N.S.W., 2070.

ELECTION TO MEMBERSHIP

BEATTIE, David Raymond Hamilton, B.Sc. (Syd.), B.E., M.Eng. Sc. (N.S.W.), 858 Henry Lawson Drive, Picnic Point, N.S.W., 2213.

BLAXLAND, David George, M.B., B.S.(Syd.), 2 Curagul Road, North Turramurra, N.S.W., 2074.

FELTON, Elizabeth Anne, B.Sc.(A.N.U.), F.G.A.A., 24 Pidcock Street, Camperdown, N.S.W., 2050.

FROST, Janet Patricia, B.A., Dip.Ed., 5 Gregory Ave., Baulkham Hills, N.S.W., 2153.

GILLESPIE, Peter James, B.Sc., B.E. (Syd.), 8 Alexander Ave., Mosman, N.S.W., 2088.

KING, David Stephen, B.Sc., 24 Doomben Ave., Eastwood, N.S.W., 2122.

LANDER, John, M.B., B.S., B.Sc.(Med.), Ph.D. 19 Dalton Rd., St. Ives, N.S.W., 2075.

LARKIN, Peter Joseph, B.Sc., Dip.Ed., 9-53 Oxford Street, Mortdale, N.S.W., 2223.

PARTRIDGE, Alan Douglas, B.Sc., M.Sc., c/- Esso Australia Ltd., G.P.O. Box 4047, Sydney, N.S.W. 2001.

RICKARD, Kevin, M.B., B.S., F.R.A.C.P., R.R.C.P.A., M.R.C. Path., F.C.A.P., 17 Blackbutts Road, French's Forest, N.S.W., 2086.

ROBINSON, Thelma Ruth, 62/4 Macleay Street, Potts Point, N.S.W., 2011.

SCOTT, Martin Edward, 4 Walker Ave., Edgecliff, N.S.W., 2027.

SUTHERLAND, Frederick Linstead, c/- The Australian Museum, 6-8 College Street, Sydney, 2000.

WILSON, Ian Robert, B.A. (Macq.), 14 Penshurst Ave., Neutral Bay, N.S.W., 2089.

YATES, Daniel Alan, 6/22 Queenscliff Road, Queenscliff, N.S.W., 2096.

ELECTION TO ASSOCIATE MEMBERSHIP

SCHÖN, Richard Willem, 80 Moss St., West Ryde, N.S.W., 2114.

YATES, Jennifer Aileen, 6/22 Queenscliff Road, Queenscliff, N.S.W., 2096.

DEATHS

BOOKER, Frederick William, D.Sc. (1951)

McGREGOR, Gordon Howard (1940)

McMAHON, Patrick Reginald, Ph.D. (1947)

# Obituaries

## PATRICK REGINALD McMAHON

Patrick Reginald McMahon was born at Havelock, New Zealand, on 11th August, 1912. He graduated Bachelor and Master of Agricultural Science from Massey Agricultural College and Ph.D. from Leeds University, England. Following post-doctoral research at Leeds, he was Wool Metrologist to the New Zealand D.S.I.R. between 1938 and 1947. In 1947 he moved to Australia to become Lecturer-in-Charge of the Sheep & Wool Department of the N.S.W. Department of Technical Education. He was appointed Foundation Professor of Wool Technology in the University of New South Wales in 1951. He established the School of Wool and Pastoral Sciences, which, under his leadership, developed a unique character, emphasising integrated education in wool technology and animal production.

He retired from the University in July,1977 and was made Emeritus Professor. In 1976 he was elected as a Fellow of both the Australian Institute of Agricultural Science and the Australian Society of Animal Production.

Professor McMahon was a pioneer in research and industrial application of the objective measurement of wool. His knowledge and experience of the textile industry made him keenly aware of the opportunities offered to wool producers, buyers and manufacturers by the adoption of wool metrology. The recent acceptance of objective criteria for classification and marketing of wool has been the culmination of research by himself and his students and colleagues and of his enthusiastic dissemination of the virtues of objective measurement to producers, buyers and processors. In addition, his foresight in establishing university level education in wool science has meant that trained personnel were available to develop and implement wool testing and new methods of wool marketing.

Professor McMahon also was a pioneer in the application of quantitative genetics to sheep breeding. His research on the estimation of genetic parameters in the New Zealand Romney was one of the first studies of this kind in the world. His active encouragement has facilitated the many distinguished contributions in theoretical and applied aspects of sheep breeding made by staff, students and graduates of the School of Wool and Pastoral Sciences. Conscious also of the need to apply sound genetic principles in the sheep industry, he established and promoted the Flock Testing Service in the University of New South Wales to provide assistance to stud masters.

Professor McMahon, a member of the Royal Society of New South Wales since 1947, had a friendly outgoing personality and had developed a wide circle of friends. He will be sadly missed by his colleagues.

F.C. Beavis

## ARTHUR BACHE WALKOM

A.B. Walkom was born in Grafton, N.S.W. on 8th February, 1889. Moving to Sydney he attended the old Fort Street Model School. His father, an amateur conchologist, took Walkom while still a lad to meetings of the Naturalists' Club. No doubt this was one of the factors that influenced him to enter a science course at Sydney University and choose geology and chemistry as his major subjects. He was appointed junior demonstrator on graduating with first class honours in geology and second class honours in chemistry. He shared the university medal with W.R. Browne.

Among his earliest research was a petrographic study of the volcanic rocks of the Pokolbin area done jointly with Browne. At this time he also published the results of petrographic and chemical studies on Antarctic rocks collected by Edgeworth David on the Shackleton expedition. Despite these contributions, his interests turned to palaeontology, stratigraphy and palaeogeology. This was in the brief period 1912-1913 when he held the position of Linnaean Macleay Fellow.

In March 1913 he was appointed lecturer under H.C. Richards, in the University of Queensland Department of Geology, established only two years before. During his stay in Queensland it became apparent to him that Australian fossil plants in the past had almost entirely been worked on by overseas palaeobotanists and from then on he made this his specialised field of work. The major contribution of his career was the "Geology of the Lower Mesozoic Rocks of Queensland with special reference to their distribution and fossil flora" which gained him his D.Sc. from the University of Sydney in 1918.

In 1919 he succeeded J.J. Fletcher as Secretary of the Linnaean Society in Sydney. He undertook other administrative duties. From 1926-1947 he was the secretary of the Australian Association for the Advancement of Science, eventually renamed the Australian and New Zealand Association for the Advancement of Science (ANZAAS). He was the first editor of the Australian Journal of Science published by ANZAAS.

Besides these administrative tasks, he continued his palaeobotanical research, extending his studies of Mesozoic and Upper Palaeozoic fossil floras into Eastern Australia generally.

Walkom was fortunate in having the opportunity to travel overseas more extensively than was usual in the period.

In 1926 he studied for a year in Cambridge under Professor A.C. Seward. He attended two International Geological Congresses in succession, that in South Africa in 1929 (the first ever held in the Southern Hemisphree) and that in Washington D.C., in 1933.

After a brief period as a Trustee of The Australian Museum he was appointed Director in November 1940, following the retirement of Dr. Charles Anderson. He held this position until November 1954, about two months short of his 66th birthday.

In this period he became involved in work for UNESCO and attended a conference in Beirut in 1948. He also attended Science Congresses in New Zealand (1949) and Bangalore, India (1951).

Acknowledgement of his long years of service to ANZAAS came when he was elected President of that body in 1949 at the Hobart meeting. He was awarded the ANZAAS medal in 1970.

Walkom had a long association with the Royal Society of New South Wales. He joined originally in 1911-12 and then rejoined in 1919, becoming a Life Member. He was President in 1943. He was awarded the Clarke Medal (1948) for his research and the Society's medal (1953) for his contributions to the organisation of Australian science.

Well into his retirement he acted as honorary treasurer for the Linnaean Society and as honorary editor of the Proceedings.

He died in Sydney on 2nd July, 1976. T.G. Vallane has written a detailed biography of A.B. Walkom (Linnean Society's Memorial Series (Vol. 102, Pt. 3).

R.O. Chalmers

Erratum: - Omission in Vol. $110^3/4$: The obituary for E. Ritchie was compiled by W.E. Taylor.

## THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library; awards of Prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special Meetings are held for the Pollock Memorial Lecture in Physics and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology.

Membership is open to any interested person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personally known.

Membership categories are:

Ordinary Members: $18.00 per annum plus $3 application fee.

Absentee Members: $15.00 per annum plus $3 application fee.

Associate Members (spouses of members and persons under 25 years of age): $5.00 per annum plus $2 application fee.

Associate Members (with Journal): $12.00 per annum plus $2 application fee.

Subscription to the Journal, which is published in four Parts per year, issued twice yearly in May and November, for non-members is $22 p.a. plus postage.

For application forms for membership and enquiries *re* subscriptoins, write to:

The Royal Society of New South Wales,
Science Centre,
35 Clarence Street,
Sydney, 2000, N.S.W.

The Society welcomes manuscripts of research (and occasional review articles) in all branches of science, art, literature and philosophy, for publication in the Journal and Proceedings.

Manuscripts will be accepted from both members and non-members, though those from the latter should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the above address.

# Contents



Publicity Press Ltd., 29-31 Meagher Street, Chippendale, Sydney.

# Journal and Proceedings of the Royal Society of New South Wales

VOLUME 111 1978 PARTS 3 and 4

Published by the Society
Science Centre, 35 Clarence Street, Sydney
Issued 20th December, 1978

# NOTICE TO AUTHORS

A "Style Guide to Authors" is available from the Honorary Secretary, Royal Society of New South Wales, 157 Gloucester Street, Sydney, N.S.W. 2000, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarized below.

## GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgments must be made.

Offset printing with "Typeset-it-Yourself" preparation of a master manuscript suitable for photography is used in the production of the Journal. Authors will be supplied with a set of special format paper. An IBM Selectric (Golf Ball) typewriter with ADJUTANT 12 typeface must be used. Biological and reference material are shown in *Light Italic*. Symbol 12 has most type required for mathematical expressions and formulae. Detailed instructions for the typist are included in the Style Guide.

## PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on heavy bond A4 paper. A second copy of both text and illustrations is required for office use. This may be a clear carbon or photographic copy. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgments and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; name(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgments; references; appendices; name of Institution/Organisation where work carried out/or private address as applicable; date manuscript received by the Society. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australia[n] Standard AS1000.

All stratigraphic names must conform with th[e] Australian Code of Stratigraphic Nomenclature (revise[d] fourth edition) and must first be cleared with th[e] Central Register of Australian Stratigraphic Name[s] Bureau of Mineral Resources, Geology and Geophysic[s] Canberra. The letter of approval should be submitte[d] with the manuscript.

*Abstract.* A brief but fully informative abstract mus[t] be provided.

*Tables* should be adjusted for size to fit the forma[t] paper of the final publication. Units of measuremen[t] should always be indicated in the headings of th[e] columns or rows to which they apply. Tables shoul[d] be numbered (serially) with Arabic numerals and mus[t] have a caption.

*Illustrations.* When submitting a paper for reviev[w] all illustrations should be in the form and size intende[d] for insertion in the master manuscript. If this is no[t] readily possible then an indication of the require[d] reduction (such as reduce to ½ size) must be clearl[y] stated.

*Note:* There is a reduction of 30% from the maste[r] manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not b[e] larger than a single page. However, large figures ca[n] be printed across two opposite pages.

Drawings should be made in black Indian ink o[n] white drawing paper, tracing cloth or light-blue line[d] graph paper. All lines and hatching or stippling shoul[d] be even and sufficiently thick to allow appropriat[e] reduction without loss of detail. The scale of map[s] or diagrams must be given in bar form.

Half-tone illustrations (photographs) should b[e] included only when essential and should be presente[d] on glossy paper (no negative is required).

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

*References* are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow the preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Abbreviations of titles of periodicals shall be in accordance with the International Standard Organization IS04 "International Code for the Abbreviation of Titles of Periodicals" and International Standard Organization IS0333 "International List of Periodical Title Word Abbreviations" and as amended.

*Appendices* should be placed at the end of the paper, be numbered in Arabic numerals, have a caption and be referred to in the text.

*Reprints.* An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

Journal and Proceedings, Royal Society of New South Wales, Vol. 111, pp. 61-64, 1978

# Proper Motions in the Region of the Galactic Cluster NGC 2516

D. S. King

ABSTRACT. Relative proper motions of stars in the region of the galactic cluster NGC 2516 based on plates taken with the 33 cm astrograph, are determined with the aim of identifying stars which are non-members. The relative proper motions have an average standard error of 0".07/century and reveal 19 likely non-members and 100 likely members.

## INTRODUCTION

The open cluster NGC 2516 (R.A. = $7^h\ 56^m.7$, Dec. = $-60^\circ\ 38'$, 1900; $l = 241^\circ.2$, $b = -15^\circ.5$) has been the subject of numerous spectroscopic and photometric investigations due to its abundance of peculiar stars. Cox (1955) studied it photovisually and more recently UBV studies have been published by Dach (1970), Eggen (1972) and Snowden (1975). The present investigation seeks to identify from their proper motions, those stars that are not members of the cluster.

## THE PLATES

The plates were taken with the 33 cm standard astrograph (scale 1' = 1 mm) as follows:

| | Plate No. | Date Taken | Exposure | Plate Pair |
|---|---|---|---|---|
| 1 | 1235s | 1894 Feb. 5 | 3 m | 3 |
| 2 | 1235s | 1894 Feb. 5 | 1½ m | 4 |
| 3 | 2816s | 1896 Feb. 21 | 3 m | 1 |
| 4 | 2816s | 1896 Feb. 21 | 1½ m | 2 |
| 5 | 2863s | 1896 Mar. 16 | 30 m | 5 |
| 6 | 7703Sa | 1977 Dec. 12 | 10 m | 4 |
| 7 | 7704Sa | 1977 Dec. 12 | 8 m | 2 |
| 8 | 7711Sa | 1978 Feb. 7 | 15 m | 5 |
| 9 | 7713Sa | 1978 Feb. 8 | 15 m | 3 |
| 10 | 7714Sa | 1978 Feb. 8 | 15 m | 1 |

Plate pairs 1 and 2 were centred at R.A. $8^h\ 00^m$ Dec. $-60^\circ\ 00'$ (1900). Plate pairs 3, 4 and 5 were centred at R.A. $7^h\ 52^m$ Dec. $-61^\circ\ 00'$ (1900).

## MEASUREMENT

The plates were each measured in a Grubb-Parsons photoelectric measuring machine in both direct and reverse positions. The reverse positions were converted into direct measures using plate constants and the average was recorded. All stars measured were selected from the published coordinates in the Astrographic Catalogue (Sydney Observatory 1954, plate N1011). The plates were measured by Mrs. A. Brown, Mrs J. Close, Miss D. Teale and Mr. D. King.

## REDUCTIONS AND PROBABILITIES

If $X_1$, $X_2$ are the measures of x on the new and old plates, $\mu$ is the annual proper motion and t is the time interval between the plates, then we can write:- $X_1 - X_2 = \mu t + ax + by + c + dm$ with a similar expression for $Y_1 - Y_2$ where x, y are taken from the new plate measures and m (magnitude) is taken from the Astrographic Catalogue. A least squares solution without the proper motion term was then calculated using all the stars measured on that plate pair. The solution was performed with a Diehl Alphatronic programmable calculator. Those stars whose residuals exceed 2.5 times the standard deviation of the residuals are eliminated from the solution and a further least squares solution sought of the remaining stars. This was continued until the standard deviation of the residuals was comparable with the accuracy of the measurements i.e. approximately 0".15/century. The resultant proper motion plate constants were then used to give the proper motions relative to the mean motion of the cluster. This is converted to a centennial proper motion by multiplying by 100k/t where k is the scale factor to convert the measured differences to seconds of arc.

A weight was assigned to each of the plate pairs by using the method of Sanders (1971) to determine the distribution parameters of a bivariate gaussian frequency function which represents the calculated field and cluster star relative proper motions. The cluster star dispersion is assumed circular and its value is used as the weight of its corresponding plate pair. Thus, the weighted mean proper motions and standard errors are determined. The distribution parameters in arc sec./century after eliminating 9 stars with very large proper motions were:

$$\theta = 10^\circ \quad N_f = 10 \quad X_f = 0.181 \quad \Sigma_x = 0.432$$
$$\sigma_c = 0.104 \quad N_c = 100 \quad Y_f = -0.261 \quad \Sigma_y = 0.725$$

$\theta$ is the rotation angle of the observed proper motions ($+\mu_x$ to $+\mu_y$) into a new coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions. All the other parameters are defined in this new coordinate system. $\sigma_c$ is the dispersion of the cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars; $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions. These parameters were then used to obtain a star's probability of membership.

The standard errors for individual stars have been grouped by their magnitudes, and the mean of the standard errors $\sigma_x$, $\sigma_y$ determined for different ranges are as follows:-

| Magnitude | $\sigma_x$ | $\sigma_y$ | No. of stars |
|---|---|---|---|
| | (Unit 0".01/cent) | | |
| 11.1 - 11.5 | 8.15 | 7.46 | 26 |
| 10.1 - 10.9 | 6.91 | 6.50 | 34 |
| 9.0 - 9.9 | 6.32 | 6.34 | 41 |
| 5.6 - 8.8 | 8.17 | 8.83 | 18 |
| All | 7.17 | 7.01 | 119 |

The absolute proper motion of the cluster by comparison with 28 Cape Catalogue stars yields + 0.25 ± 0.17"/cent. in R.A. and + 0.77 ± 0.22"/cent. in Dec. In agreement with Cox's estimates of + 0.14 ± 0.16"/cent. in R.A. and + 0.81 ± 0.15"/cent. in Dec.

The observational data follows in table 1. The various columns are:-

No. The number from the Astrographic Catalogue, Sydney Section ($8^h\ 00^m$ - $60^o$ centre).
Mag. The magnitude of the star as determined by the image diameter.
R.A. Right ascension (1950), all prefixed by 7 hours.
Dec. Declination (1950), all prefixed by - 60 degrees.
CPD No. Prefixed by - $60^o$.
V Photovisual magnitude from Cox.
C No. Cox number.
$\mu_x, \mu_y$ Centennial proper motion in units of 0".01/cent. The axes are parallel to R.A. and Dec.
$\sigma_x, \sigma_y$ Standard errors of centennial proper motion in units of 0".01/cent.
P Probability of membership.
Notes 6 - Not used in calculation of distribution parameters.

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TABLE 1

THE OBSERVATIONAL DATA

| No. | Mag. | R.A. | Dec. | CPD No. | V | C No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 102 | 10.9 | 58 30 | 50 15 | | 10.85 | 32 | - 4 | 4 | 8 | 6 | 99 | |
| 104 | 9.7 | 57 49 | 52 34 | 1001 | 9.44 | 33 | 6 | - 6 | 4 | 8 | 99 | |
| 105 | 10.3 | 57 41 | 49 05 | 994 | 10.39 | 34 | 6 | -10 | 8 | 5 | 99 | |
| 106 | 11.3 | 56 56 | 48 08 | | | | 8 | 10 | 9 | 8 | 99 | |
| 107 | 11.1 | 56 49 | 48 45 | | | | 6 | 11 | 9 | 3 | 99 | |
| 108 | 10.3 | 56 46 | 51 24 | 958 | 10.30 | 98 | 3 | - 3 | 4 | 5 | 99 | |
| 109 | 10.7 | 56 43 | 51 19 | 956 | 10.94 | 99 | -20 | -17 | 10 | 9 | 94 | |
| 112 | 10.5 | 55 59 | 48 42 | | 10.90 | 4 | -12 | - 2 | 3 | 6 | 99 | |
| 115 | 11.1 | 55 24 | 48 37 | | | | 149 | 244 | 12 | 7 | 0 | 6 |
| 116 | 11.4 | 54 57 | 49 08 | | | | 33 | 5 | 1 | 5 | 67 | |
| 118 | 10.5 | 54 30 | 49 33 | 926 | | | -15 | 3 | 10 | 7 | 99 | |
| 134 | 9.9 | 58 26 | 43 49 | 1013 | 9.90 | 28 | - 1 | 6 | 4 | 2 | 99 | |
| 136 | 11.1 | 58 01 | 46 52 | | 11.20 | 69 | 8 | 12 | 10 | 1 | 99 | |
| 138 | 11.1 | 57 58 | 43 23 | | 11.31 | 56 | - 2 | 2 | 7 | 12 | 99 | |
| 139 | 10.3 | 57 43 | 45 37 | 996 | 10.51 | 35 | 2 | - 4 | 7 | 3 | 99 | |
| 140 | 9.7 | 57 35 | 44 17 | 989 | 9.41 | 36 | 11 | 3 | 5 | 6 | 99 | |
| 141 | 7.2 | 57 33 | 43 13 | 988 | | | - 4 | 21 | 3 | 16 | 98 | |
| 142 | 8.6 | 57 24 | 44 14 | 985 | 8.21 | 37 | 7 | -10 | 5 | 6 | 99 | |
| 143 | 9.7 | 57 21 | 43 45 | 981 | 9.50 | 38 | 8 | - 7 | 8 | 8 | 99 | |
| 145 | 6.7 | 56 56 | 47 24 | 967 | 7.05 | B | - 8 | -17 | 8 | 11 | 98 | |
| 146 | 11.3 | 56 49 | 45 15 | 962 | 11.25 | 96 | 7 | 14 | 10 | 11 | 99 | |
| 147 | 9.0 | 56 49 | 46 21 | 961 | 8.78 | 2 | - 1 | - 5 | 5 | 10 | 99 | |
| 148 | 10.7 | 56 48 | 45 42 | 958 | 10.91 | 97 | -25 | 5 | 5 | 4 | 96 | |
| 151 | 9.5 | 56 22 | 45 11 | 949 | 9.46 | 3 | - 6 | 5 | 5 | 2 | 99 | |
| 152 | 10.9 | 56 15 | 45 36 | | | | 68 | -139 | 11 | 13 | 0 | |
| 154 | 10.9 | 55 44 | 45 02 | | | | 19 | -91 | 3 | 4 | 0 | |
| 157 | 9.5 | 54 32 | 42 37 | 927 | | | - 4 | 0 | 3 | 9 | 99 | |
| 176 | 9.3 | 59 13 | 38 13 | 1023 | 9.15 | 63 | -20 | -196 | 5 | 9 | 0 | 6 |
| 176B | 10.2 | 59 13 | 38 00 | | 9.97 | 64 | -23 | -198 | 8 | 12 | 0 | 6 |
| 177 | 11.5 | 59 06 | 41 09 | | | | 3 | -13 | 11 | 8 | 99 | |
| 178 | 9.5 | 58 37 | 39 30 | 1017 | 9.60 | 24 | 0 | 7 | 7 | 5 | 99 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | C No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 179 | 10.1 | 58 33 | 39 16 | 1016 | 9.84 | 25 | 82 | 70 | 4 | 6 | 0 | |
| 180 | 9.3 | 58 31 | 40 40 | 1015 | 9.08 | 26 | 6 | 4 | 8 | 4 | 99 | |
| 181 | 10.7 | 58 15 | 41 48 | 1011 | 10.38 | 27 | -280 | -39 | 12 | 6 | 0 | 6 |
| 182 | 10.7 | 58 13 | 39 33 | 1010 | 10.77 | 21 | - 6 | 3 | 9 | 4 | 99 | |
| 183 | 5.6 | 58 01 | 41 13 | 1006 | 5.81 | A | -12 | 3 | 11 | 23 | 99 | |
| 184 | 10.3 | 57 54 | 38 21 | 1004 | 10.52 | 53 | -45 | -104 | 4 | 12 | 0 | |
| 185 | 11.5 | 57 47 | 42 04 | | 11.65 | 72 | 19 | 4 | 4 | 4 | 98 | |
| 186 | 10.5 | 57 44 | 41 12 | 997 | 10.56 | 54 | - 1 | - 3 | 9 | 12 | 99 | |
| 188 | 8.8 | 57 37 | 39 54 | 990 | 8.54 | d | 14 | 11 | 5 | 3 | 99 | |
| 189 | 11.1 | 57 30 | 41 25 | 987 | 10.96 | 55 | 0 | - 2 | 6 | 9 | 99 | |
| 190 | 7.1 | 57 23 | 39 52 | 982 | 7.38 | b | -19 | -15 | 7 | 12 | 96 | |
| 192 | 8.1 | 57 20 | 40 48 | 980 | 6.71 | a | -18 | 17 | 12 | 9 | 97 | |
| 193 | 8.6 | 57 18 | 38 38 | 979 | 8.42 | 83 | - 9 | 5 | 6 | 5 | 99 | |
| 194 | 11.3 | 57 18 | 38 21 | | 10.71 | 84 | 13 | 29 | 7 | 11 | 79 | |
| 196 | 9.3 | 57 13 | 40 35 | 978 | 8.94 | c | - 7 | 0 | 8 | 7 | 99 | |
| 198 | 9.3 | 57 09 | 42 34 | 975 | 9.01 | 1 | - 4 | - 6 | 7 | 6 | 99 | |
| 199 | 9.7 | 56 59 | 40 46 | 970 | 9.59 | 94 | - 9 | 0 | 8 | 5 | 99 | |
| 200 | 9.0 | 56 56 | 41 24 | 968 | 9.17 | 41 | - 3 | -21 | 7 | 5 | 97 | |
| 201 | 11.4 | 56 56 | 40 29 | | 11.16 | 93 | -15 | 18 | 6 | 4 | 97 | |
| 202 | 10.7 | 56 56 | 38 52 | 965 | 10.66 | 42 | - 8 | 12 | 7 | 7 | 99 | |
| 203 | 11.5 | 56 55 | 39 42 | | 11.69 | 95 | 8 | 14 | 14 | 6 | 99 | |
| 205 | 9.9 | 56 39 | 42 14 | 954 | 9.90 | 40 | - 3 | - 1 | 6 | 4 | 99 | |
| 206 | 11.5 | 56 34 | 41 29 | | 11.31 | 107 | 21 | 0 | 5 | 10 | 98 | |
| 207 | 8.6 | 56 31 | 37 53 | 953 | 7.80 | 10 | 0 | - 9 | 9 | 8 | 99 | |
| 208 | 9.7 | 56 30 | 40 37 | 952 | 9.28 | 9 | 13 | 8 | 4 | 5 | 99 | |
| 211 | 9.5 | 56 10 | 38 54 | 948 | 9.70 | 8 | -10 | - 5 | 6 | 4 | 99 | |
| 212 | 9.0 | 55 58 | 42 19 | 945 | 8.56 | 5 | 3 | - 6 | 6 | 7 | 99 | |
| 213 | 9.5 | 55 57 | 40 51 | | | | 16 | -12 | 12 | 10 | 98 | |
| 214 | 9.3 | 55 56 | 40 47 | 944 | | | 11 | -14 | 8 | 7 | 99 | |
| 215 | 9.9 | 55 53 | 40 44 | | 9.88 | 112 | 9 | - 9 | 4 | 5 | 99 | |
| 216 | 11.4 | 55 49 | 40 43 | | 11.28 | 104 | 23 | 10 | 10 | 4 | 95 | |
| 217 | 9.7 | 55 49 | 38 27 | 942 | 10.03 | 7 | 2 | - 5 | 5 | 5 | 99 | |
| 219 | 9.3 | 55 31 | 39 57 | 939 | 8.96 | 6 | - 1 | - 4 | 2 | 3 | 99 | |
| 220 | 11.1 | 55 03 | 38 04 | 931 | | | -165 | 313 | 7 | 6 | 0 | 6 |
| 244 | 8.6 | 59 07 | 36 30 | 1022 | 8.35 | 23 | 7 | - 3 | 6 | 8 | 99 | |
| 245 | 10.7 | 59 05 | 33 40 | 1021 | 10.81 | 67 | - 2 | - 1 | 10 | 6 | 99 | |
| 248 | 7.8 | 57 53 | 33 51 | 1003 | 7.87 | 19 | 20 | 9 | 5 | 7 | 97 | |
| 250 | 10.7 | 57 44 | 33 51 | 998 | 10.32 | 52 | - 9 | - 4 | 5 | 4 | 99 | |
| 251 | 9.0 | 57 41 | 35 31 | 993 | 8.77 | 48 | 7 | 6 | 7 | 7 | 99 | |
| 252 | 9.5 | 57 39 | 33 38 | 991 | 9.74 | 77 | -15 | - 1 | 8 | 6 | 99 | |
| 253 | 11.1 | 57 36 | 36 32 | | 9.87 | 49 | 51 | -41 | 5 | 7 | 0 | |
| 254 | 11.5 | 57 28 | 37 02 | | 11.44 | 111 | 0 | 7 | 12 | 10 | 99 | |
| 255 | 9.9 | 57 25 | 37 05 | 986 | 10.08 | 50 | - 8 | - 2 | 4 | 5 | 99 | |
| 256 | 9.7 | 57 24 | 35 20 | 984 | 9.68 | 47 | - 1 | 2 | 4 | 6 | 99 | |
| 259 | 10.7 | 57 12 | 35 28 | | 10.43 | 46 | 6 | - 8 | 7 | 6 | 99 | |
| 260 | 9.5 | 57 07 | 37 15 | 973 | 9.39 | 43 | 5 | 2 | 4 | 7 | 99 | |
| 261 | 9.9 | 57 07 | 36 05 | 974 | 9.88 | 45 | 1 | 3 | 7 | 5 | 99 | |
| 262 | 10.7 | 57 02 | 36 55 | 972 | 10.94 | 44 | - 3 | - 1 | 6 | 4 | 99 | |
| 263 | 9.7 | 56 59 | 35 06 | 971 | 9.68 | 58 | 0 | 7 | 7 | 7 | 99 | |
| 264 | 10.3 | 56 51 | 35 28 | 963 | 10.24 | 57 | 3 | - 1 | 5 | 5 | 99 | |
| 265 | 10.3 | 55 18 | 34 09 | 934 | | | 15 | 3 | 7 | 10 | 99 | |
| 291 | 10.1 | 59 17 | 32 41 | 1025 | 10.14 | 66 | -12 | - 8 | 10 | 8 | 99 | |
| 292 | 11.5 | 59 12 | 29 05 | | | | 30 | 6 | 8 | 3 | 82 | |
| 293 | 9.5 | 58 53 | 32 01 | 1019 | 9.60 | 22 | -12 | - 6 | 7 | 7 | 99 | |
| 294 | 10.7 | 58 01 | 31 48 | 1007 | 10.85 | 51 | - 6 | - 9 | 7 | 8 | 99 | |
| 295 | 9.5 | 58 00 | 30 21 | 1005 | | | - 4 | -12 | 15 | 4 | 99 | |
| 296 | 9.7 | 57 59 | 30 25 | | | | 26 | 14 | 7 | 10 | 86 | |
| 297 | 9.5 | 57 47 | 31 07 | 1000 | 9.60 | 18 | 2 | - 2 | 6 | 10 | 99 | |
| 298 | 10.7 | 57 40 | 29 33 | 992 | 10.63 | 60 | 1 | 9 | 4 | 5 | 99 | |
| 300 | 10.7 | 57 24 | 30 50 | 983 | 10.50 | 59 | -34 | -99 | 8 | 6 | 0 | |
| 302 | 7.8 | 57 12 | 28 42 | 976 | 7.72 | 15 | - 4 | 6 | 7 | 3 | 99 | |
| 303 | 11.5 | 57 01 | 30 57 | | 11.58 | 90 | 314 | -781 | 5 | 15 | 0 | 6 |
| 304 | 8.8 | 56 59 | 32 50 | 969 | 8.59 | 11 | 13 | - 4 | 7 | 10 | 99 | |
| 305 | 8.8 | 56 57 | 28 24 | 966 | 8.40 | 91 | -12 | - 6 | 9 | 8 | 99 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | C No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 306 | 9.7 | 56 53 | 29 40 | 964 | 9.44 | 14 | - 5 | 14 | 9 | 6 | 99 | |
| 307 | 9.5 | 56 41 | 29 42 | 955 | 9.21 | 12 | 5 | 8 | 10 | 8 | 99 | |
| 308 | 11.4 | 56 35 | 31 08 | | 11.44 | 92 | 7 | -10 | 5 | 11 | 99 | |
| 310 | 11.1 | 56 13 | 28 29 | | 11.31 | 108 | -20 | 3 | 9 | 11 | 99 | |
| 311 | 8.6 | 56 04 | 27 47 | 947 | 8.16 | 13 | - 4 | -13 | 11 | 8 | 99 | |
| 313 | 10.7 | 55 52 | 29 44 | 943 | | | 19 | 76 | 10 | 6 | 0 | |
| 314 | 9.7 | 55 28 | 28 22 | 936 | | | - 5 | 0 | 5 | 6 | 99 | |
| 316 | 11.4 | 55 21 | 28 25 | | | | 17 | 17 | 5 | 9 | 96 | |
| 318 | 10.3 | 54 36 | 31 57 | 928 | | | 214 | -541 | 6 | 5 | 0 | 6 |
| 344 | 6.9 | 58 46 | 26 56 | 1018 | 5.21 | 110 | 20 | 27 | 10 | 9 | 68 | |
| 348 | 8.8 | 58 24 | 26 58 | 1012 | 8.38 | 20 | 14 | 12 | 13 | 9 | 99 | |
| 349 | 9.9 | 58 02 | 27 56 | 1008 | 9.78 | 17 | - 5 | 0 | 4 | 7 | 99 | |
| 350 | 11.3 | 57 53 | 23 52 | | | | -304 | 214 | 12 | 5 | 0 | 6 |
| 351 | 10.7 | 57 47 | 25 26 | 999 | 10.94 | 109 | 8 | -13 | 8 | 9 | 99 | |
| 352 | 9.3 | 57 44 | 25 53 | 995 | 9.67 | 16 | -20 | -11 | 7 | 5 | 97 | |
| 353 | 11.1 | 57 11 | 24 39 | | | | 8 | - 8 | 13 | 4 | 99 | |
| 354 | 11.1 | 56 58 | 27 28 | | | | 20 | 21 | 10 | 10 | 88 | |
| 356 | 10.1 | 56 28 | 26 41 | 951 | 10.32 | 101 | -10 | -17 | 5 | 4 | 98 | |
| 358 | 10.7 | 55 46 | 25 17 | | | | - 1 | 0 | 4 | 7 | 99 | |
| 359 | 10.7 | 55 33 | 22 44 | 940 | | | 2 | - 7 | 2 | 3 | 99 | |
| 361 | 7.8 | 55 28 | 23 30 | 935 | | | 8 | 22 | 13 | 4 | 97 | |
| 362 | 10.1 | 55 13 | 23 23 | 933 | | | 11 | - 7 | 9 | 4 | 99 | |
| 363 | 9.0 | 54 17 | 24 43 | 924 | | | -101 | 178 | 6 | 7 | 0 | 6 |
| 389 | 9.3 | 55 01 | 19 35 | 930 | | | -55 | 10 | 5 | 11 | 0 | |

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# Precise Observations of Minor Planets at Sydney Observatory During 1977

T. L. MORGAN

ABSTRACT. Positions of 2 Pallas, 3 Juno, 11 Parthenope, 18 Melpomene, 39 Laetitia, 148 Gallia and 704 Interamnia obtained with the 23 cm camera are given.

The programme of precise observations of selected minor planets begun by W.H. Robertson in 1955 is being continued and the results for 1977 are given here. The methods of observation are described in the first paper (Robertson 1958). All the plates were taken with the 23 cm camera (scale 116" to the millimeter). Four exposures were taken on each plate, except those for 704 Interamnia which had two exposures.

In Table 1 are given the means of the positions for all the exposures for each of two separate groups of reference stars at the mean of the exposure times. The differences in the results for the two groups of reference stars average $0^s.028$ sec $\delta$ in right ascension and 0".50 in declination. This leads to probable errors for the mean of the two results on the one plate of $0^s.012$ sec $\delta$ in right ascension and 0".21 in declination.

The result for the first pair of images was compared with the results for the last pair by adding the motion computed from the ephemeris for the plates with four exposures and by comparing the first and last image for the plates with two exposures. The means of the differences were $0^s.020$ sec $\delta$ in right ascension and 0".24 in declination. It is expected that the two results will be combined before they are used. However, they are published in the present form so that any correction to the positions of the reference stars may be conveniently applied by using the dependences from Table 2.

No correction has been applied for aberration, light time or parallax, but the factors give the parallax correction when divided by the distances. The column headed "O-C" gives the differences between the measured positions (corrected for parallax) and the position computed from the ephemerides supplied by the Institute for Theoretical Astronomy in Leningrad.

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table 2 gives for each observation the positions of the reference stars and the dependences. The column headed "R.A." and "Dec." give the seconds of time and arc with the proper motion correction supplied to bring the catalogue position to the epoch of the plate. The column headed "Star" gives the Durchmusterung number taken from either the AGK3 or SAO catalogue. The first column gives a serial number which cross-references Table 1 and Table 2 and also the catalogue from which the reference stars were taken.

All plates were reduced by both the methods of dependences and by first order plate constants using the same six reference stars. The r.m.s. residuals of the reference stars were 0".3 for AGK3 stars and 0".5 for SAO stars.

The plates were measured by Mrs A. Brown, Miss J. Fitt and Miss D. Teale who also assisted with the reductions. The observers at the telescope were D.S. King (K), T.L. Morgan (M), W.H. Robertson (R) and K.P. Sims (S).

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TABLE 1

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | |
|---|---|---|---|---|---|---|---|---|
| | 2 Pallas 1977 U.T. | | | | | | | |
| 1507 | Mar. 10.47240 | 08 37 22.845 | -07 29 38.74 | -0.003 | -3.86 | -0.05 | -0.5 | M |
| 1508 | Mar. 10.47240 | 08 37 22.834 | -07 29 39.28 | | | | | |
| 1509 | Mar. 14.46362 | 08 37 30.851 | -05 45 25.17 | +0.003 | -4.10 | -0.07 | -0.9 | M |
| 1510 | Mar. 14.46362 | 08 37 30.814 | -05 45 24.55 | | | | | |
| 1511 | Mar. 22.45160 | 08 39 16.052 | -02 26 04.97 | +0.030 | -4.55 | -0.10 | -0.5 | R |
| 1512 | Mar. 22.45160 | 08 39 16.043 | -02 26 05.53 | | | | | |

TABLE 1 (Cont.)

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | |
|---|---|---|---|---|---|---|---|---|
| | 2 Pallas (Cont.) 1977 U.T. | | | | | | | |
| 1513 | Apr. 04.40865 | 08 46 07.264 | +02 18 25.74 | -0.008 | -5.15 | -0.02 | -0.4 | K |
| 1514 | Apr. 04.40865 | 08 46 07.229 | +02 18 25.72 | | | | | |
| | 3 Juno 1977 U.T. | | | | | | | |
| 1515 | Mar. 28.72678 | 16 00 20.495 | -06 38 34.74 | -0.014 | -3.98 | -0.03 | +0.3 | R |
| 1516 | Mar. 28.72678 | 16 00 20.540 | -06 38 34.71 | | | | | |
| 1517 | Apr. 13.69118 | 15 55 08.742 | -05 05 03.20 | +0.022 | -4.20 | -0.03 | +0.4 | M |
| 1518 | Apr. 13.69118 | 15 55 08.721 | -05 05 03.25 | | | | | |
| 1519 | May 24.57019 | 15 25 23.182 | -01 38 48.76 | +0.058 | -4.65 | +0.01 | +0.4 | S |
| 1520 | May 24.57019 | 15 25 23.182 | -01 38 49.11 | | | | | |
| 1521 | June 16.47076 | 15 10 05.034 | -01 08 01.52 | -0.022 | -4.71 | -0.07 | 0.0 | R |
| 1522 | June 16.47076 | 15 10 05.048 | -01 08 01.90 | | | | | |
| 1523 | June 22.46176 | 15 07 23.716 | -01 12 33.54 | +0.006 | -4.70 | -0.07 | -0.3 | S |
| 1524 | June 22.46176 | 15 07 23.714 | -01 12 33.63 | | | | | |
| 1525 | July 14.39722 | 15 03 23.854 | -02 06 39.32 | +0.001 | -4.59 | -0.01 | -0.3 | K |
| 1526 | July 14.39722 | 15 03 23.876 | -02 06 40.09 | | | | | |
| 1527 | July 21.37832 | 15 04 03.916 | -02 33 51.78 | 0.000 | -4.53 | -0.02 | -0.2 | K |
| 1528 | July 21.37832 | 15 04 03.912 | -02 33 51.94 | | | | | |
| 1529 | Aug. 04.34867 | 15 08 01.530 | -03 38 19.56 | +0.018 | -4.39 | -0.06 | +0.2 | R |
| 1530 | Aug. 04.34867 | 15 08 01.506 | -03 38 19.74 | | | | | |
| | 11 Parthenope 1977 U.T. | | | | | | | |
| 1531 | Apr. 27.75743 | 18 22 12.666 | -18 11 34.88 | +0.032 | -2.35 | -0.03 | +0.1 | R |
| 1532 | Apr. 27.75743 | 18 22 12.646 | -18 11 35.65 | | | | | |
| 1533 | May 24.69034 | 18 20 09.528 | -18 01 15.90 | +0.058 | -2.39 | -0.05 | +0.2 | S |
| 1534 | May 24.69034 | 18 20 09.593 | -18 01 15.85 | | | | | |
| 1535 | June 16.59115 | 18 02 31.962 | -18 25 52.66 | -0.020 | -2.31 | -0.01 | +0.5 | R |
| 1536 | June 16.59115 | 18 02 31.999 | -18 25 52.39 | | | | | |
| 1537 | June 22.57473 | 17 56 38.069 | -18 37 02.18 | -0.007 | -2.28 | -0.05 | +0.1 | S |
| 1538 | June 22.57473 | 17 56 38.114 | -18 37 01.72 | | | | | |
| 1539 | July 13.51837 | 17 37 52.793 | -19 26 38.30 | +0.038 | -2.16 | -0.07 | +0.5 | K |
| 1540 | July 13.51837 | 17 37 52.760 | -19 26 38.00 | | | | | |
| 1541 | July 19.49543 | 17 34 07.412 | -19 43 06.68 | +0.025 | -2.12 | -0.06 | -0.1 | M |
| 1542 | July 19.49543 | 17 34 07.403 | -19 43 07.12 | | | | | |
| 1543 | Aug. 04.43951 | 17 29 30.236 | -20 30 30.32 | -0.004 | -2.00 | -0.01 | -0.5 | R |
| 1544 | Aug. 04.43951 | 17 29 30.260 | -20 30 30.90 | | | | | |
| 1545 | Aug. 15.41692 | 17 31 10.876 | -21 04 41.60 | +0.016 | -1.92 | -0.04 | -0.5 | S |
| 1546 | Aug. 15.41692 | 17 31 10.930 | -21 04 42.68 | | | | | |
| 1547 | Aug. 19.40700 | 17 32 45.540 | -21 17 06.02 | +0.016 | -1.89 | -0.03 | -0.5 | K |
| 1548 | Aug. 19.40700 | 17 32 45.560 | -21 17 05.54 | | | | | |
| | 18 Melpomene 1977 U.T. | | | | | | | |
| 1549 | Mar. 28.76360 | 16 55 40.578 | -09 46 15.62 | -0.019 | -3.56 | -0.01 | +0.2 | R |
| 1550 | Mar. 28.76360 | 16 55 40.534 | -09 46 16.89 | | | | | |
| 1551 | Apr. 13.72910 | 16 57 56.658 | -08 29 05.32 | +0.005 | -3.74 | -0.05 | +0.3 | M |
| 1552 | Apr. 13.72910 | 16 57 56.706 | -08 29 05.89 | | | | | |
| 1553 | Apr. 27.68156 | 16 54 13.678 | -07 15 14.48 | -0.016 | -3.91 | -0.02 | +0.4 | R |
| 1554 | Apr. 27.68156 | 16 54 13.666 | -07 15 14.24 | | | | | |
| 1555 | May 24.59720 | 16 33 35.674 | -05 14 01.98 | -0.004 | -4.18 | +0.02 | +0.2 | S |
| 1556 | May 24.59720 | 16 33 35.660 | -05 14 01.20 | | | | | |
| 1557 | June 16.50973 | 16 10 54.104 | -04 44 34.46 | -0.032 | -4.24 | -0.02 | +0.1 | R |
| 1558 | June 16.50973 | 16 10 54.095 | -04 44 33.06 | | | | | |
| 1559 | July 14.42386 | 15 54 45.815 | -06 11 00.72 | -0.027 | -4.05 | +0.01 | +0.7 | K |
| 1560 | July 14.42386 | 15 54 45.830 | -06 10 59.58 | | | | | |
| 1561 | July 19.42012 | 15 54 05.262 | -06 38 03.40 | +0.005 | -3.99 | 0.00 | -0.4 | M |
| 1562 | July 19.42012 | 15 54 05.275 | -06 38 03.28 | | | | | |

TABLE 1 (Cont.)

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | |
|---|---|---|---|---|---|---|---|---|
| | 18 Melpomene (Cont.) 1977 U.T. | | | | | | | |
| 1563 | Aug. 08.37191 | 15 58 21.934 | -08 47 29.02 | +0.016 | -3.69 | -0.01 | -0.1 | K |
| 1564 | Aug. 08.37191 | 15 58 21.890 | -08 47 28.40 | | | | | |
| 1565 | Aug. 15.37287 | 16 02 19.819 | -09 38 04.41 | +0.070 | -3.58 | +0.01 | +0.5 | S |
| 1566 | Aug. 15.37287 | 16 02 19.804 | -09 38 04.28 | | | | | |
| | 39 Laetitia 1977 U.T. | | | | | | | |
| 1567 | Apr. 13.76183 | 18 00 29.580 | -10 39 10.84 | -0.025 | -3.44 | -0.02 | +0.5 | M |
| 1568 | Apr. 13.76183 | 18 00 29.584 | -10 39 12.16 | | | | | |
| 1569 | Apr. 18.74688 | 18 01 49.645 | -10 19 10.65 | -0.035 | -3.49 | -0.05 | 0.0 | K |
| 1570 | Apr. 18.74688 | 18 01 49.680 | -10 19 11.28 | | | | | |
| 1571 | Apr. 27.72253 | 18 02 45.288 | -09 43 21.62 | -0.036 | -3.57 | -0.02 | -0.1 | R |
| 1572 | Apr. 27.72253 | 18 02 45.313 | -09 43 20.95 | | | | | |
| 1573 | May 24.66737 | 17 53 56.598 | -08 14 00.24 | +0.040 | -3.78 | -0.03 | -0.3 | S |
| 1574 | May 24.66737 | 17 53 56.634 | -08 14 00.52 | | | | | |
| 1575 | June 16.56836 | 17 36 00.145 | -07 49 15.30 | -0.033 | -3.83 | +0.03 | -0.5 | R |
| 1576 | June 16.56836 | 17 36 00.116 | -07 49 15.28 | | | | | |
| 1577 | June 22.55638 | 17 30 48.162 | -07 53 46.52 | -0.008 | -3.82 | +0.03 | -0.8 | S |
| 1578 | June 22.55638 | 17 30 48.170 | -07 53 46.04 | | | | | |
| 1579 | July 13.49756 | 17 15 12.706 | -08 45 27.36 | +0.020 | -3.70 | +0.03 | +0.2 | K |
| 1580 | July 13.49756 | 17 15 12.692 | -08 45 27.38 | | | | | |
| 1581 | Aug. 04.41807 | 17 08 09.710 | -10 25 34.48 | -0.025 | -3.46 | -0.07 | +0.5 | R |
| 1582 | Aug. 04.41807 | 17 08 09.672 | -10 25 34.60 | | | | | |
| 1583 | Aug. 08.41876 | 17 08 09.834 | -10 46 54.38 | +0.011 | -3.41 | -0.03 | +0.1 | K |
| 1584 | Aug. 08.41876 | 17 08 09.810 | -10 46 56.10 | | | | | |
| | 148 Gallia 1977 U.T. | | | | | | | |
| 1585 | Sep. 12.77134 | 04 07 07.252 | -11 00 29.76 | -0.009 | -3.40 | +0.01 | +0.2 | R |
| 1586 | Sep. 12.77134 | 04 07 07.279 | -11 00 30.09 | | | | | |
| 1587 | Oct. 05.73068 | 04 19 11.651 | -16 06 40.70 | +0.030 | -2.66 | +0.11 | -0.4 | M |
| 1588 | Oct. 05.73068 | 04 19 11.630 | -16 06 40.64 | | | | | |
| 1589 | Oct. 17.68099 | 04 19 06.938 | -18 43 22.95 | -0.024 | -2.28 | +0.04 | +0.6 | R |
| 1590 | Oct. 17.68099 | 04 19 06.934 | -18 43 23.31 | | | | | |
| 1591 | Nov. 07.62367 | 04 08 50.976 | -22 06 18.16 | -0.001 | -1.77 | -0.03 | 0.0 | K |
| 1592 | Nov. 07.62367 | 04 08 50.946 | -22 06 17.85 | | | | | |
| 1593 | Nov. 16.58588 | 04 01 40.470 | -22 44 59.60 | -0.029 | -1.68 | -0.04 | -0.3 | R |
| 1594 | Nov. 16.58588 | 04 01 40.548 | -22 44 57.90 | | | | | |
| 1595 | Dec. 05.55012 | 03 45 57.188 | -22 06 22.38 | +0.061 | -1.79 | -0.02 | +1.5 | S |
| 1596 | Dec. 05.55012 | 03 45 57.212 | -22 06 21.90 | | | | | |
| 1597 | Dec. 08.53774 | 03 43 49.132 | -21 45 46.42 | +0.052 | -1.84 | 0.00 | +1.1 | S |
| 1598 | Dec. 08.53774 | 03 43 49.182 | -21 45 46.44 | | | | | |
| | 704 Interamnia 1977 U.T. | | | | | | | |
| 1599 | Feb. 14.65233 | 11 13 22.770 | -18 16 34.64 | +0.017 | -2.31 | +0.03 | -0.3 | S |
| 1600 | Feb. 14.65283 | 11 13 22.628 | -18 16 34.60 | | | | | |
| 1601 | Mar. 16.54730 | 10 50 11.877 | -17 21 09.26 | -0.006 | -2.45 | -0.05 | 0.0 | K |
| 1602 | Mar. 16.54730 | 10 50 11.888 | -17 21 09.72 | | | | | |
| 1603 | Mar. 21.54774 | 10 46 28.311 | -16 57 42.96 | +0.048 | -2.52 | -0.05 | -0.8 | S |
| 1604 | Mar. 21.54774 | 10 46 28.328 | -16 57 42.72 | | | | | |
| 1605 | Apr. 18.44713 | 10 32 19.803 | -14 18 35.15 | +0.002 | -2.89 | -0.06 | -0.6 | M |
| 1606 | Apr. 18.44713 | 10 32 19.832 | -14 18 35.69 | | | | | |

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Star | Depend. | R.A. | Dec. |
|---|---|---|---|---|
| 1507 | - 6 2667 | 0.359253 | 37.493 | 48.90 |
| SAO | - 7 2566 | 0.361856 | 42.959 | 22.41 |
| | - 8 2465 | 0.278890 | 30.947 | 02.55 |
| 1508 | - 6 2658 | 0.321363 | 26.906 | 51.63 |
| SAO | - 7 2570 | 0.326820 | 08.067 | 33.41 |
| | - 6 2700 | 0.351816 | 17.292 | 56.76 |
| 1509 | - 5 2602 | 0.310624 | 23.328 | 53.89 |
| SAO | - 4 2411 | 0.354454 | 56.387 | 35.54 |
| | - 6 2690 | 0.334922 | 10.094 | 46.17 |
| 1510 | - 5 2599 | 0.312743 | 09.836 | 05.44 |
| SAO | - 4 2415 | 0.370928 | 42.450 | 47.94 |
| | - 6 2686 | 0.316329 | 37.235 | 01.79 |
| 1511 | - 1 2099 | 0.344048 | 23.779 | 04.42 |
| SAO | - 3 2430 | 0.304294 | 45.298 | 41.64 |
| | - 1 2124 | 0.351657 | 24.365 | 08.90 |
| 1512 | - 1 2102 | 0.303704 | 49.639 | 23.93 |
| SAO | - 3 2432 | 0.317813 | 02.953 | 09.78 |
| | - 1 2119 | 0.378483 | 26.702 | 03.57 |
| 1513 | + 3 2045 | 0.334536 | 56.317 | 34.55 |
| AGK3 | + 1 2170 | 0.331338 | 32.044 | 07.56 |
| | + 3 2080 | 0.334125 | 53.388 | 05.32 |
| 1514 | + 2 2061 | 0.347558 | 31.697 | 34.02 |
| AGK3 | + 3 2055 | 0.289276 | 23.192 | 39.79 |
| | + 2 2080 | 0.363167 | 11.187 | 34.61 |
| 1515 | - 6 4333 | 0.360698 | 26.913 | 39.06 |
| SAO | - 5 4220 | 0.339928 | 58.502 | 05.23 |
| | - 7 4191 | 0.299374 | 14.980 | 13.56 |
| 1516 | - 5 4215 | 0.381092 | 20.164 | 56.62 |
| SAO | - 6 4338 | 0.317392 | 44.289 | 18.45 |
| | - 7 4194 | 0.301517 | 34.698 | 07.64 |
| 1517 | - 4 3996 | 0.358497 | 31.924 | 30.92 |
| SAO | - 4 4014 | 0.319214 | 59.127 | 15.88 |
| | - 5 4215 | 0.322290 | 20.164 | 56.62 |
| 1518 | - 3 3846 | 0.296739 | 52.242 | 07.18 |
| SAO | - 5 4200 | 0.350758 | 39.061 | 04.66 |
| | - 4 4019 | 0.352504 | 33.213 | 24.81 |
| 1519 | - 1 3053 | 0.322960 | 52.964 | 43.96 |
| AGK3 | - 2 3998 | 0.306452 | 06.498 | 55.38 |
| | - 0 2977 | 0.370588 | 40.038 | 17.82 |
| 1520 | - 0 2964 | 0.357623 | 45.094 | 45.67 |
| AGK3 | - 2 4001 | 0.352339 | 02.449 | 47.69 |
| | - 0 2973 | 0.290038 | 50.423 | 53.93 |
| 1521 | - 0 2930 | 0.332218 | 41.504 | 23.92 |
| SAO | - 0 2943 | 0.325732 | 47.546 | 46.31 |
| | - 1 3043 | 0.342050 | 40.588 | 56.83 |
| 1522 | - 0 2934 | 0.331396 | 55.683 | 04.98 |
| SAO | - 0 2942 | 0.303694 | 34.281 | 55.22 |
| | - 0 2946 | 0.364910 | 32.694 | 21.94 |
| 1523 | - 0 2930 | 0.347474 | 41.504 | 23.92 |
| SAO | - 1 3027 | 0.373567 | 52.234 | 40.18 |
| | - 0 2941 | 0.278960 | 13.180 | 40.72 |
| 1524 | - 0 2923 | 0.306294 | 02.746 | 14.00 |
| SAO | - 1 3028 | 0.292658 | 17.579 | 58.11 |
| | - 0 2943 | 0.401048 | 47.546 | 46.31 |
| 1525 | - 1 3006 | 0.363621 | 26.700 | 05.77 |
| SAO | - 2 3949 | 0.283844 | 25.726 | 03.83 |
| | - 1 3027 | 0.352535 | 52.234 | 40.18 |
| 1526 | - 1 3012 | 0.288176 | 25.581 | 04.69 |
| SAO | - 1 3017 | 0.385069 | 41.248 | 40.66 |
| | - 2 3943 | 0.326755 | 54.811 | 28.16 |
| 1527 | - 2 3940 | 0.315584 | 14.789 | 41.57 |
| SAO | - 1 3022 | 0.374216 | 51.265 | 51.63 |
| | - 2 3946 | 0.310200 | 57.731 | 51.26 |
| 1528 | - 3 3717 | 0.312164 | 07.791 | 16.89 |
| SAO | - 1 3018 | 0.390858 | 57.299 | 41.51 |
| | - 1 3028 | 0.296978 | 17.579 | 58.11 |
| 1529 | - 2 3949 | 0.367522 | 25.726 | 03.83 |
| SAO | - 3 3735 | 0.317023 | 56.342 | 50.51 |
| | - 4 3838 | 0.315456 | 08.959 | 01.56 |
| 1530 | - 2 3944 | 0.289250 | 09.706 | 42.58 |
| SAO | - 3 3738 | 0.352884 | 40.487 | 07.37 |
| | - 3 3747 | 0.357866 | 29.801 | 42.27 |
| 1531 | -18 4928 | 0.321142 | 37.524 | 13.70 |
| SAO | -17 5194 | 0.368858 | 45.065 | 07.40 |
| | -18 4967 | 0.310000 | 05.173 | 25.26 |
| 1532 | -18 4938 | 0.303898 | 50.811 | 41.95 |
| SAO | -17 5173 | 0.334908 | 25.999 | 51.69 |
| | -18 4976 | 0.361194 | 51.416 | 25.95 |
| 1533 | -18 4931 | 0.357150 | 44.842 | 34.93 |
| SAO | -17 5173 | 0.311260 | 25.999 | 51.69 |
| | -18 4944 | 0.331591 | 24.990 | 18.11 |
| 1534 | -18 4914 | 0.364526 | 49.840 | 10.65 |
| SAO | -17 5172 | 0.331389 | 13.165 | 37.98 |
| | -18 4967 | 0.304086 | 05.173 | 25.26 |
| 1535 | -18 4752 | 0.323648 | 46.192 | 44.47 |
| SAO | -19 4842 | 0.330074 | 59.147 | 13.48 |
| | -17 5033 | 0.346278 | 36.057 | 06.47 |
| 1536 | -17 5000 | 0.318012 | 14.862 | 43.77 |
| SAO | -19 4829 | 0.309361 | 12.592 | 24.77 |
| | -18 4795 | 0.372628 | 45.061 | 00.23 |
| 1537 | -18 4715 | 0.317724 | 14.970 | 02.25 |
| SAO | -19 4792 | 0.301527 | 43.519 | 36.12 |
| | -18 4752 | 0.380749 | 46.192 | 44.47 |
| 1538 | -19 4776 | 0.376256 | 47.340 | 45.83 |
| SAO | -18 4738 | 0.310213 | 12.116 | 13.10 |
| | -17 5000 | 0.313531 | 14.862 | 43.77 |
| 1539 | -19 4674 | 0.299629 | 10.750 | 44.45 |
| SAO | -18 4618 | 0.362367 | 22.605 | 01.00 |
| | -19 4690 | 0.338004 | 44.174 | 02.91 |
| 1540 | -20 4831 | 0.267788 | 49.918 | 45.87 |
| SAO | -18 4595 | 0.316363 | 49.638 | 08.33 |
| | -19 4695 | 0.415850 | 45.831 | 25.23 |
| 1541 | -18 4580 | 0.319129 | 01.411 | 39.85 |
| SAO | -20 4814 | 0.344316 | 24.038 | 48.96 |
| | -19 4677 | 0.336554 | 54.324 | 39.56 |
| 1542 | -20 4802 | 0.359005 | 41.380 | 15.93 |
| SAO | -20 4828 | 0.341467 | 10.179 | 40.20 |
| | -18 4595 | 0.299527 | 49.638 | 08.33 |
| 1543 | -21 4622 | 0.303702 | 16.613 | 22.25 |
| SAO | -20 4785 | 0.361258 | 00.747 | 03.86 |
| | -20 4812 | 0.335040 | 56.452 | 21.75 |
| 1544 | -20 4776 | 0.321518 | 25.495 | 26.71 |
| SAO | -19 4656 | 0.307790 | 46.924 | 04.63 |
| | -21 4654 | 0.370691 | 59.576 | 57.93 |
| 1545 | -21 4640 | 0.358060 | 00.827 | 43.00 |
| SAO | -20 4802 | 0.349002 | 41.380 | 15.93 |
| | -21 4654 | 0.292938 | 59.576 | 57.93 |
| 1546 | -21 4644 | 0.371636 | 20.989 | 13.76 |
| SAO | -20 4790 | 0.303856 | 26.940 | 44.39 |
| | -21 4662 | 0.324508 | 49.394 | 10.65 |
| 1547 | -21 4644 | 0.332791 | 20.989 | 13.76 |
| SAO | -21 4665 | 0.331250 | 22.492 | 52.47 |
| | -20 4823 | 0.335958 | 32.023 | 37.82 |
| 1548 | -21 4638 | 0.357577 | 39.298 | 18.59 |
| SAO | -20 4813 | 0.325666 | 10.628 | 20.90 |
| | -21 4684 | 0.316758 | 49.532 | 42.44 |
| 1549 | -11 4237 | 0.352338 | 47.088 | 11.04 |
| SAO | - 8 4365 | 0.360836 | 13.397 | 58.25 |
| | - 9 4481 | 0.286826 | 46.606 | 44.09 |
| 1550 | -10 4413 | 0.313746 | 58.318 | 26.08 |
| SAO | - 8 4362 | 0.395875 | 48.465 | 02.90 |
| | - 9 4478 | 0.290378 | 41.709 | 29.05 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Star | Depend. | R.A. | Dec. | No. | Star | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1551 | - 8 4366 | 0.324682 | 11.028 | 42.78 | 1573 | - 7 4515 | 0.363542 | 00.795 | 15.51 |
| SAO | - 7 4383 | 0.311884 | 48.834 | 53.63 | SAO | - 9 4624 | 0.314906 | 07.642 | 15.19 |
| | - 8 4380 | 0.363433 | 29.489 | 51.70 | | - 7 4540 | 0.321551 | 13.666 | 01.81 |
| 1552 | - 8 4360 | 0.340304 | 32.925 | 28.26 | 1574 | - 8 4521 | 0.311128 | 53.617 | 02.21 |
| SAO | - 8 4374 | 0.372037 | 12.393 | 18.80 | SAO | - 7 4533 | 0.369570 | 07.889 | 56.28 |
| | - 8 4379 | 0.287660 | 20.006 | 32.70 | | - 8 4538 | 0.319301 | 41.735 | 39.40 |
| 1553 | - 7 4364 | 0.331071 | 28.988 | 41.10 | 1575 | - 7 4462 | 0.360838 | 18.131 | 36.22 |
| SAO | - 8 4360 | 0.287248 | 32.925 | 28.26 | SAO | - 8 4482 | 0.348316 | 17.060 | 57.26 |
| | - 6 4537 | 0.381681 | 05.821 | 44.16 | | - 7 4483 | 0.290846 | 04.029 | 48.47 |
| 1554 | - 7 4370 | 0.396858 | 18.338 | 25.05 | 1576 | - 6 4612 | 0.274534 | 37.317 | 38.41 |
| SAO | - 6 4522 | 0.221982 | 17.416 | 31.33 | SAO | - 8 4478 | 0.354550 | 43.393 | 36.04 |
| | - 7 4387 | 0.381160 | 48.993 | 49.68 | | - 7 4485 | 0.370916 | 31.129 | 54.26 |
| 1555 | - 5 4317 | 0.412950 | 39.641 | 52.40 | 1577 | - 8 4447 | 0.374530 | 16.459 | 37.58 |
| SAO | - 4 4129 | 0.308934 | 57.362 | 04.21 | SAO | - 6 4612 | 0.332282 | 37.317 | 38.41 |
| | - 4 4143 | 0.278116 | 16.667 | 17.51 | | - 8 4468 | 0.293188 | 22.696 | 32.38 |
| 1556 | - 5 4316 | 0.446689 | 55.210 | 24.66 | 1578 | - 6 4600 | 0.323150 | 16.048 | 22.66 |
| SAO | - 5 4328 | 0.206799 | 39.854 | 56.04 | SAO | - 8 4456 | 0.300494 | 20.151 | 35.19 |
| | - 4 4139 | 0.346512 | 48.210 | 37.07 | | - 8 4471 | 0.376355 | 05.222 | 40.23 |
| 1557 | - 5 4246 | 0.348173 | 26.107 | 22.42 | 1579 | - 7 4414 | 0.359302 | 21.770 | 27.58 |
| SAO | - 3 3902 | 0.349613 | 38.776 | 51.84 | SAO | - 9 4527 | 0.280301 | 54.905 | 32.68 |
| | - 5 4271 | 0.302214 | 10.961 | 55.51 | | - 8 4429 | 0.360398 | 04.036 | 17.62 |
| 1558 | - 4 4061 | 0.295214 | 00.520 | 17.79 | 1580 | - 9 4522 | 0.306814 | 11.345 | 37.64 |
| SAO | - 3 3888 | 0.376084 | 36.314 | 37.56 | SAO | - 8 4417 | 0.377896 | 23.488 | 44.99 |
| | - 5 4276 | 0.328702 | 08.343 | 23.55 | | - 8 4427 | 0.315290 | 56.018 | 37.10 |
| 1559 | - 4 3996 | 0.354465 | 31.923 | 30.92 | 1581 | - 9 4502 | 0.351840 | 19.947 | 34.02 |
| SAO | - 6 4316 | 0.323525 | 21.580 | 38.82 | SAO | -11 4316 | 0.289077 | 33.299 | 06.09 |
| | - 6 4338 | 0.322010 | 44.270 | 18.46 | | -10 4460 | 0.359084 | 48.206 | 14.53 |
| 1560 | - 7 4134 | 0.400824 | 56.203 | 50.67 | 1582 | -11 4305 | 0.354236 | 07.966 | 03.59 |
| SAO | - 5 4206 | 0.333002 | 37.950 | 10.62 | SAO | - 9 4510 | 0.404676 | 29.375 | 23.68 |
| | - 5 4213 | 0.266174 | 55.168 | 47.48 | | - 9 4518 | 0.241086 | 34.440 | 01.01 |
| 1561 | - 6 4313 | 0.342218 | 13.805 | 41.10 | 1583 | -10 4442 | 0.330044 | 47.446 | 48.28 |
| SAO | - 6 4316 | 0.320802 | 21.580 | 38.82 | SAO | - 9 4510 | 0.338267 | 29.375 | 23.68 |
| | - 5 4201 | 0.336980 | 41.909 | 03.25 | | -11 4323 | 0.331688 | 11.707 | 16.49 |
| 1562 | - 7 4130 | 0.367303 | 52.037 | 20.04 | 1584 | - 9 4501 | 0.264580 | 01.238 | 27.74 |
| SAO | - 5 4200 | 0.337830 | 39.060 | 04.66 | SAO | -11 4315 | 0.418403 | 13.362 | 44.89 |
| | - 6 4333 | 0.294867 | 26.912 | 39.06 | | -10 4456 | 0.317016 | 14.313 | 31.78 |
| 1563 | - 9 4265 | 0.336200 | 44.372 | 06.75 | 1585 | -11 802 | 0.383066 | 12.920 | 32.20 |
| SAO | - 8 4136 | 0.373286 | 00.056 | 23.30 | SAO | -10 851 | 0.274813 | 05.204 | 33.69 |
| | - 8 4139 | 0.290513 | 27.027 | 30.44 | | -11 825 | 0.342120 | 16.712 | 54.07 |
| 1564 | - 7 4150 | 0.317500 | 53.031 | 05.95 | 1586 | -10 844 | 0.265085 | 17.999 | 30.66 |
| SAO | - 9 4278 | 0.325748 | 03.132 | 52.41 | SAO | -11 805 | 0.396150 | 32.709 | 54.50 |
| | - 8 4144 | 0.356752 | 46.384 | 16.27 | | -11 828 | 0.338766 | 23.859 | 10.95 |
| 1565 | -10 4230 | 0.336828 | 02.961 | 41.18 | 1587 | -17 839 | 0.317356 | 31.167 | 15.31 |
| SAO | - 8 4144 | 0.320080 | 46.384 | 16.27 | SAO | -15 768 | 0.372476 | 09.395 | 30.10 |
| | - 9 4304 | 0.343091 | 05.110 | 27.42 | | -16 852 | 0.310169 | 58.963 | 15.23 |
| 1566 | - 9 4278 | 0.373011 | 03.132 | 52.41 | 1588 | -16 829 | 0.339156 | 24.350 | 44.19 |
| SAO | -10 4252 | 0.329572 | 00.315 | 40.30 | SAO | -15 769 | 0.341759 | 10.572 | 51.21 |
| | - 8 4165 | 0.297416 | 58.629 | 07.61 | | -17 875 | 0.319085 | 16.040 | 46.82 |
| 1567 | -11 4507 | 0.314780 | 10.088 | 37.29 | 1589 | -19 875 | 0.357496 | 06.499 | 15.52 |
| SAO | - 9 4644 | 0.340826 | 41.585 | 25.04 | SAO | -19 900 | 0.343892 | 16.317 | 05.76 |
| | -10 4602 | 0.344394 | 19.911 | 35.16 | | -17 867 | 0.298611 | 21.536 | 46.33 |
| 1568 | -11 4510 | 0.292437 | 33.023 | 29.34 | 1590 | -17 837 | 0.299208 | 54.771 | 15.10 |
| SAO | -10 4587 | 0.350489 | 34.461 | 36.96 | SAO | -19 886 | 0.359015 | 44.773 | 59.04 |
| | -10 4611 | 0.357074 | 47.782 | 48.11 | | -18 832 | 0.341777 | 12.221 | 54.00 |
| 1569 | -10 4590 | 0.311586 | 17.799 | 42.49 | 1591 | -22 1490 | 0.238464 | 44.166 | 11.91 |
| SAO | - 9 4643 | 0.352654 | 39.884 | 56.11 | SAO | -22 1495 | 0.399687 | 45.615 | 03.11 |
| | -11 4532 | 0.335759 | 25.443 | 30.93 | | -22 1523 | 0.361848 | 26.381 | 48.55 |
| 1570 | -10 4592 | 0.287850 | 28.010 | 51.96 | 1592 | -22 1488 | 0.337243 | 28.788 | 57.15 |
| SAO | -10 4602 | 0.397002 | 19.911 | 35.16 | SAO | -22 1509 | 0.408182 | 43.979 | 24.14 |
| | - 9 4646 | 0.315149 | 26.002 | 58.21 | | -22 1512 | 0.254575 | 34.268 | 16.57 |
| 1571 | - 8 4547 | 0.315283 | 56.000 | 14.76 | 1593 | -22 1432 | 0.353156 | 50.831 | 46.93 |
| SAO | -10 4602 | 0.350034 | 19.911 | 35.16 | SAO | -23 1712 | 0.304030 | 08.712 | 06.83 |
| | - 9 4654 | 0.334684 | 51.746 | 37.67 | | -23 1739 | 0.342814 | 02.912 | 49.99 |
| 1572 | - 9 4643 | 0.360024 | 39.884 | 56.11 | 1594 | -23 1686 | 0.327160 | 14.827 | 12.81 |
| SAO | -10 4600 | 0.351808 | 47.652 | 20.60 | SAO | -23 1729 | 0.377458 | 40.016 | 48.31 |
| | - 8 4562 | 0.288168 | 17.002 | 25.27 | | -22 1468 | 0.295381 | 10.718 | 09.57 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Star | Depend. | R.A. | Dec. | No. | Star | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1595 | -21 695 | 0.356116 | 08.367 | 51.69 | 1601 | -16 3130 | 0.342352 | 02.074 | 18.48 |
| SAO | -22 1336 | 0.371531 | 10.988 | 33.44 | SAO | -16 3143 | 0.330204 | 36.239 | 00.66 |
| | -23 1591 | 0.272352 | 02.604 | 28.36 | | -17 3259 | 0.327444 | 10.249 | 06.69 |
| 1596 | -22 1310 | 0.350646 | 17.675 | 07.88 | 1602 | -16 3136 | 0.345780 | 42.004 | 16.42 |
| SAO | -21 704 | 0.367338 | 36.645 | 09.91 | SAO | -17 3252 | 0.321128 | 04.793 | 16.85 |
| | -22 1353 | 0.282015 | 24.418 | 06.28 | | -16 3145 | 0.333092 | 51.588 | 22.74 |
| 1597 | -21 677 | 0.337634 | 26.592 | 12.95 | 1603 | -15 2131 | 0.342638 | 53.597 | 53.01 |
| SAO | -22 1309 | 0.328098 | 15.796 | 54.11 | SAO | -17 3244 | 0.327800 | 00.184 | 34.21 |
| | -22 1347 | 0.334268 | 48.344 | 21.24 | | -16 3136 | 0.329562 | 42.004 | 16.42 |
| 1598 | -22 1293 | 0.311125 | 06.119 | 21.36 | 1604 | -16 3121 | 0.383842 | 49.560 | 36.62 |
| SAO | -21 687 | 0.297359 | 58.130 | 36.09 | SAO | -15 3140 | 0.340320 | 21.437 | 16.40 |
| | -21 704 | 0.391516 | 36.645 | 09.91 | | -16 3139 | 0.275838 | 12.856 | 49.97 |
| 1599 | -17 3324 | 0.352442 | 16.393 | 07.71 | 1605 | -14 3138 | 0.348870 | 39.032 | 41.36 |
| SAO | -18 3143 | 0.313816 | 40.276 | 27.57 | SAO | -14 3146 | 0.384314 | 39.247 | 42.49 |
| | -17 3351 | 0.333742 | 23.889 | 15.37 | | -13 3170 | 0.266816 | 03.151 | 02.18 |
| 1600 | -18 3131 | 0.350293 | 34.723 | 43.00 | 1606 | -13 3138 | 0.341871 | 58.986 | 13.06 |
| SAO | -16 3211 | 0.304896 | 45.250 | 43.74 | SAO | -14 3149 | 0.276271 | 46.499 | 50.76 |
| | -17 3352 | 0.344810 | 38.218 | 18.09 | | -13 3172 | 0.381858 | 16.870 | 47.84 |

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# The Minor Planets*

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ABSTRACT. The discovery and observation of the minor planets is summarised and a review given of our present knowledge of their orbits, masses, diameters and surface properties.

## HISTORICAL

The history of the minor planets or asteroids, dates from the discovery of a regularity in the orbits of the planets, often referred to as Bode's Law, but which was first formulated by Johann Titius in 1772. If the distances of the planets are set out in order, then approximately, if the mean distance of Mercury from the Sun is taken as 4 units, the distance of Venus is 4 + 3 = 7, Earth is 4 + 6 = 10, Mars 4 + 12 = 16 and so on. The system works quite well as far as Saturn, except that there was a very obvious gap at the point 4 + 24. When Uranus was discovered by Herschel in 1781 and was found to fit the scheme quite well, it strengthened the idea that a missing planet could exist in the gap. It should be mentioned that the scheme breaks down completely in the case of Neptune and Pluto. Around the end of the 18th century a search for the missing planet was organised by a German astronomer, von Zach. A number of European astronomers began searching the sky for such a body but the final discovery of the first minor planet came about accidentally on the first day of the 19th century - 1st January, 1801, when Piazzi was observing stars at Palermo on the island of Sicily to form a star catalogue. He first noticed a star-like object, measured its position, and on the next night found that it had apparently moved. He continued to observe it for some time and initially thought it might be an unusual kind of comet; he did not inform other astronomers until 24th January and as the mails were rather slow, nobody else was able to observe it before it became lost in the evening twilight. Piazzi himself was able to observe it only until 11th February, after which he was taken ill. Thus there was a considerable risk that the object which had now been called Ceres would be lost so soon after it had been discovered. Several people tried to calculate orbits but they differed considerably from one another.

The challenge was taken up by Carl Friedrich Gauss, who although quite a young man was already known for his work in mathematics - especially in algebra and theory of numbers. He had had some ideas on the subject of calculating the orbit of a planet from a limited number of observations and when he heard of the discovery of Ceres, he set to work to perfect the theory and applied it to the urgent problem. His orbit fitted the observations which Piazzi had made very much better than those which others had calculated, and he predicted where the planet would be at the end of 1801 on its next apparition. Using the predictions of Gauss, Zach first observed it again for certain on 1st January, 1802, and now that it was found there was no risk that it would be lost again. Gauss went on to improve the orbit and to calculate the perturbations caused by the gravitational attraction of the other planets. His method of calculating orbits is still the basis of the methods used for getting the orbits of newly found comets. Olbers, an amateur astronomer in Bremen, in 1802 discovered a second minor planet which was given the name Pallas, and two more were discovered in a fairly short time - Juno in 1804 by Harding and Vesta in 1807, again by Olbers. Thus there were four little planets where only one had been expected. This led to the idea that the newly discovered planets were fragments of a larger planet which had somehow broken up, and the search for other bodies was continued for some time. However, no success was achieved and the idea was dropped unti 1845 when Hencke found the fifth one, Astraea. By this time much better star charts were available and this made it easier to recognise a newly discovered star-like object as a stranger, and since 1847 not a year has passed without at least one, and often scores of new asteroids being discovered. The method of discovery was first to search the sky and compare the appearance in the telescope with the best available star chart. If a new object was found, it would be checked for movement and after a few weeks sufficient observations might be obtained for a preliminary orbit to be calculated.

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## DISCOVERY AND POSITIONAL OBSERVATION

A much more powerful method became available by the use of photography. A long exposure photograph was taken of an area of the sky and if the telescope was guided carefully, the stars would produce small, round images on the photographic plate. However, any asteroid which was present would show up as a short trail because of its motion relative to the stars. Fainter objects can be detected if the photographic plate is moved at the expected speed of a minor planet, because then the light is concentrated at one place on the plate and not spread out into a trail. A device for this purpose designed by Harley Wood, was constructed at Sydney Observatory - not for discovery, but for observation of the fainter asteroids. Concentrating the light of the minor planet means the star images now appear

as short trails. The first observer to use photography was Max Wolf, who discovered a minor planet in this way in 1891. Since then, great numbers of minor planets have been found and the number which have orbits sufficiently accurate for unmistakable prediction has now passed 2000. As can be seen from the examples already given, the names given to the minor planets were first taken from goddesses and other female persons of the Greek and Roman mythology, With the increasing number of discoveries, the supply of such people from all kinds of mythology began to run out and astronomers chose names from many other sources. They were usually given a feminine ending, although in recent years even this idea has been dropped. The exception to the feminine rule was that planets with unusual orbits were often given male mythical names, for example - Eros, Icarus and the recently discovered Chiron. Each planet is also given a number, for example : 1 Ceres, 433 Eros and 1566 Icarus. In recent years the allotting of a permanent number is not done until a sufficiently reliable orbit has been computed and usually not until the asteroid has been seen on three different apparitions. When the planet is first discovered, it is given a preliminary number of the form 1976 AA where the first A indicates that it was found in the first half of January, 1976, and the second A means that it was the first planet found in that period. After the allotment of a permanent number, the original discoverer has the right to give it a proper name. The numbers near 1000 were given rather special treatment, thus 998 is called Bodea, 999 Zachia, 1000 Piazzia, 1001 Gaussia and 1002 Olbersia. A similar plan has been adopted for those near 2000; thus 1996 Adams, 1997 Leverrier, 1998 Titius, 1999 Hirayama, 2000 Herschel, 2001 Einstein, 2002 Euler, 2003 Harding, 2004 Lexell, 2005 Hencke.

Many discoveries turn out later to be rediscoveries of bodies which have been found years before, but which have not been followed sufficiently for accurate orbits to be obtained. Until the advent of modern computing methods, the number of known minor planets had become something of a nuisance in that it was difficult to keep track of even those which were already known - let alone the continual flood of new discoveries. This situation was aggravated during the Second World War when computing and observing were very much reduced. However, from 1946 onwards, a number of observatories began again to observe the asteroids and the use of modern computers greatly speeded up the calculation of the orbits and perturbations by the major planets. The centres for the collection of observations, computing of orbits and calculation of ephemerides have been at the Astronomisches Rechen-Institut in Berlin from 1893 to 1945 and since 1946 at Cincinnati Observatory in the United States, and the Institute of Theoretical Astronomy at Leningrad, U.S.S.R. The work at Cincinnati is now being passed over to the Harvard Smithsonian Centre for Astrophysics at Cambridge, Massachusetts. Cincinnati maintained a file of all observations and the calculation and improvement of orbits and issued a series of Minor Planet Circulars which tabulated this information. Leningrad, also calculates improved orbits and publishes a yearly volume of ephemerides which gives for those minor planets which have permanent numbers their predicted positions for 10-day intervals for a period of 70 days around the time of opposition, as well as extended predictions for those of special interest.

At Sydney Observatory we first engaged in observing the general field of asteroids to secure observations which would lead to improved orbits. However, more recently the planets which need orbit improvement are almost all very faint objects which cannot be reached from an observatory in the centre of a city where long exposure photographs are impossible. Consequently, we have concentrated on getting more precise observations of a number of the brighter planets which are being used by the Institute of Theoretical Astronomy at Leningrad to obtain improved determination of fundamental constants of astronomy, such as the position of the equator and the equinox. Such observations help to determine corrections to the observed positions in star catalogues. The position of Sydney enables us to observe the asteroids in the southern part of their orbits where they are less accessible to observatories in the northern hemisphere.

ORBITS

The orbits of the minor planets lie mainly between Mars and Jupiter, with periods ranging between 3½ and 6 years, but their orbits are not as regular as those of most of the major planets, and there are some with high inclination and high eccentricity. Some of these latter ones can come well inside the orbit of Mars and in some cases approach fairly close to the Earth. As for the distances from the Sun and therefore of the periods, the distribution is not at all smooth, with significant gaps at the points where there is a resonance with Jupiter, that is where the period would be a fraction in small whole numbers of the period of Jupiter. Thus, gaps occur where this ratio is 1:3, 2:5, 3:7 and 1:2. These gaps are known as the Kirkwood gaps after their discoverer, and the explanation is that an asteroid with such a period would receive oft repeated perturbations by Jupiter which is the most massive planet in the solar system, and thus would be forced into an orbit with a period either slightly longer or slightly shorter. It has also been shown by Hirayama that a considerable fraction of the minor planets could be grouped into "families" of planets which had similar orbits. This idea was extended by Brouwer and one possible explanation is that the members of a family were once parts of a larger body which broke up because of a collision, though this cannot be regarded as proved. Another notable grouping is known as the Trojan asteroids. In his work on celestial mechanics, Joseph Lagrange predicted in the 18th century, that bodies at the same distance from the Sun as Jupiter, would be in stable orbits if they occupied positions either ahead of or behind Jupiter, in such a position that Jupiter, the Sun and the third body formed an equilateral triangle. The first body to satisfy this relationship was 588 Achilles, discovered by Wolf in 1906 and since then more than twenty Trojans have been discovered. They are called Trojans because their names are selected from heroes of the Trojan war described by Homer in the Iliad, and it is conventional to have Greek names for those near one Lagrangian point and Trojan names for those near the other. In fact, the planets do not keep strictly to the exact equilateral points but can depart considerably from them. For one thing,

Jupiter's orbit is not a circle and perturbations by Saturn also have a considerable effect.

MASSES

Because they are so small, it has proved very difficult to determine directly the mass of even the largest minor planets. The mass of an astronomical body can be determined only by its gravitational attraction on some other body. Thus, the mass of the Sun can be calculated when we know the distance of the Earth and its period around the Sun. Similarly, the mass of a planet can be found from the period and distance of its satellites. Where a planet has no satellites, its mass can be determined by its attraction on one of the other planets, which causes perturbations from the simple ellipse which the planet would follow around the Sun if there were no other forces acting on it. This method was applied in the case of Mercury, Venus and Pluto, but much more accurate masses of Mercury and Venus have now been obtained by measuring their attraction on space vehicles which have passed close by. Observations of spacecraft have also given the most accurate measures of the masses of the Moon and Mars. The perturbations of some of the minor planets have given good determinations of the mass of Jupiter. It was not until 1968 that the first measure of the mass of a minor planet, namely 4 Vesta, was made by Hertz. He used the fact that Vesta has a resonance with a small planet 197 Arete, which was discovered in 1879. Four periods of Arete total 18.13 years and five periods of Vesta total 18.15 years, so 6 times since the discovery of Arete - namely in 1885, 1903, 1921, 1939, 1957 and 1975 Vesta came within 6 million km of it. This has meant that the attraction of Vesta was sufficient to show up in the motion of Arete and to enable the mass of Vesta to be measured. A similar resonance was found between 1 Ceres and 2 Pallas which have the same period to one part in a thousand and although they do not have such close approaches as Vesta and Arete do, the long interval over which they have been observed enabled Schubart to determine their mutual attractions and so calculate their masses. The possibility of using the near equality of the periods of Ceres and Pallas to determine their masses was first suggested by Gauss soon after their discovery. The most recently determined values for these three planets expressed as fractions of the Moon's mass, are Ceres $0.0160 \pm .0008$, Pallas $0.0030 \pm .0006$ and Vesta $0.0032 \pm .0003$. No other suitable resonances are known, and in any case these are certainly the most massive of all the minor planets. In fact, it has been estimated from the measures of their sizes that more than half of the mass of the whole system of minor planets is contained in these three bodies.

PHYSICAL OBSERVATIONS

A great deal of information about the physical condition of the minor planets has been obtained by measuring the changes in their brightness. The observed brightness of an asteroid will depend on its size and reflectivity and will vary as its distance from the Sun and the Earth vary. The reflectivity of a planet is usually called the albedo, which is defined as the total amount of sunlight reflected from the body in all directions as a fraction of the amount that falls on it. For the Moon and Mercury this figure is about 0.07, for cloud covered planets it is much higher - up to 0.59 for Venus. A further factor affecting the brightness is the phase angle which is the angle at the planet between the Earth and the Sun. The variation in brightness with phase angle depends on the roughness of the surface and most minor planets are even rougher than the Moon. Careful measurements show that in addition to these variations already mentioned, a number of asteroids show variations of short period (a few hours). These can be interpreted as due to the rotation of the body and continued observation will give a reasonably accurate value for the rotation period. In some cases the amplitude of the variation has been found to vary in different parts of the planet's orbit, and this indicates that we are observing the rotation from a different aspect with respect to the planet's pole. Thus, if the Earth were in the line of the pole of rotation, the variation would be zero and if we were in the plane of the equator, the variation would be a maximum. In a few cases, using considerations of this sort, it has been possible to make a rough determination of the direction of the pole. The variations of brightness are mostly rather small - from a few percent up to about 50 percent, and only since the use of photoelectric methods has much success been achieved. There are some notable exceptions such as 433 Eros with a brightness ratio of four to one and 1620 Geographos six to one.

Because they are so small, it has not been possible until recent times to determine the diameters of more than a few of the minor planets. Between 1894 and 1900 Barnard, using a filar micrometer attached to the large telescopes at the Lick and Yerkes Observatories, measured the diameters of the first four and obtained figures as follows:- Ceres 770 km, Pallas 490 km, Juno 195 km and Vesta 390 km. However, since the visible image of even these was very small, it was always recognised that the results were very uncertain. In the last ten years, new methods have been used to determine the diameter of quite a large number of asteroids. The first method depends on measuring the amount of polarization of the reflected light from the asteroid. The light is only slightly polarized by a few percent, but the polarization varies with the phase angle and not with distance from the Sun or the Earth or with rotation. The curve of variation of polarization with phase angle is compared with the curve determined in the laboratory from various substances, including powdered materials from meteorites and from the Moon. There are considerable variations in the shape of the curves for different materials which can be correlated with the reflectivity of the material. So the reflectivity or albedo of the planet is determined and its size can then be calculated from its brightness knowing its distance from the Earth and the Sun.

A second method, which now gives good agreement with the polarization method, is to measure the brightness of the minor planet in visible light, and also in infrared at a wave-length of about 10 μm. Of the light received by a planet, part is reflected and the remainder is absorbed and heats the surface of the planet. The amount of heat radiation at a wave-length of 10 μm is determined by the planet's surface temperature. Clearly, a dark body will reflect poorly at visible wave lengths and absorb more of the light with increase of temperature

and so give off a greater amount of heat.

By these means it has been found that the minor planets can mainly be divided into two groups which are referred to as S and C class. The S class have an albedo of approximately 0.15 comparable to the reflectivity of silicate rocks, whereas the C asteroids with an albedo of about 0.035 probably have a high carbon content as they are about as black as a piece of coal. Similar bodies have been found among the meteorites. There are a few asteroids which do not fit into these two main classes and some even have albedos as high as about 0.4. 4 Vesta is an example of the non-conformists with an albedo of 0.23. Once the albedos have been determined, the diameters can be calculated from the total amount of light reflected and it turns out that the figures obtained by Barnard were rather too small. The most recent results, using a mean of the polarimetric and radiometric methods, give for the diameter of the first four, Ceres 1003 km, Pallas 608 km, Juno 247 km, Vesta 538 km. Of these, Ceres is C type, Juno is S type and Pallas and Vesta are unclassified. A survey which gives results of varying quality for 187 minor planets, lists a total of 14 with diameters greater than 250 km and another 14 with diameters between 200 km and 250 km, though this second list is almost certainly incomplete. Among the first asteroids measured by these methods, the S type predominated, but more recent results show that the C class are much more numerous, especially in the outer part of the main belt. Diameters as small as 1 km have been measured for close approach planets such as 1566 Icarus and 1976 AA. For such small bodies the quantity measured should be called the effective diameter, as they are quite certainly not spherical as is shown by the variations in brightness with rotation. An additional method of obtaining information about the material in the surfaces of asteroids is by observing the reflectivity as a function of the wave-length in the region from 0.4 μm to 1.0 μm in the visible and near infrared. This spectrophotometry correlates with the albedo figures derived from the other methods. The most interesting fact is that the curves for some of the S type asteroids show a dip at 0.9 μm, corresponding to pyroxene minerals, notably pigeonite. The variation with wave-length shows that the S type asteroids are reddish brown while the C type are more neutral coloured.

Another method of checking on the diameters of minor planets is to observe occultations of the stars by a planet. Since the minor planets have such small diameters, the width of the shadow track caused by them, will necessarily be quite narrow and more often than not will occur in rather a remote place. So far only a few observations of this type have been made but there has been an upsurge of interest in the method and a number of predictions have been made for the next few years. For best results the timing should be done photoelectrically. An alternative is to observe the occultation of a minor planet by the Moon. Here too photoelectric observing will give the best results because the total time of disappearance, even for the largest asteroids, is only about 1 or 2 seconds. Unfortunately, these events are rather infrequent and can be observed only for the brightest minor planets. The picture we get of an asteroid is a body with a very rough surface, probably pitted with craters like Phobos and Deimos, the two moons of Mars and most likely covered in dust. Because of their small mass they would be quite unable to retain an atmosphere.

## NOTABLE ASTEROIDS

Finally, a little about a few particularly interesting minor planets. 433 Eros was discovered in 1898 and because of its close approaches to Earth has received much attention since then. Close approaches occurred in 1931, 26 million km, and 1975, 22.6 million km. In 1931 an international campaign was mounted to measure the distance of the little planet in order to improve the accuracy of the astronomical unit which is the mean distance of the Earth from the Sun. The attraction of the Earth, especially at the time of close approach, causes considerable perturbations to the planet's motion, and this too was used indirectly to give a measure of the astronomical unit. These methods have since been superseded by radar determinations of the distances of the nearer major planets, especially Venus. Consequently, no special effort was made to measure the distance of Eros in 1975, but extensive physical observations were made by all available methods. It was even detected by radar. When Eros is close enough, it is possible to see its shape and its rotation. This confirmed the large variations in its brightness as it rotates in a period of 5 hours 17 minutes. The observations of its size are best fitted by a spheroid whose longest and shortest diameters are 36 km and 12 km.

1566 Icarus was discovered in 1949 when it was quite close to the Earth. It was moving very rapidly but sufficient observations were obtained to enable an orbit to be calculated. It has a very elongated orbit which takes it beyond the orbit of Mars, but at its closest to the Sun inside the orbit of Mercury. Its orbit is considerably tilted and when it crosses the Earth's orbit the two orbits are separated by 6 million km. Its period is just over one year and 18 of its periods are almost exactly equal to 19 years. This means that close approaches occur every 19 years, the most recent one being in 1968 and at that time it was very extensively observed.

1976 AA was discovered at the beginning of 1976 at Palomar Mountain as a result of systematic searching for objects which come close to the Earth. It was the first asteroid discovered with a mean distance and period less than that of the Earth; it has a period of 0.950 years. At the time of its discovery it was only 18 million km from the Earth, which is as close as it can come. Because of the similarity of the two orbits, 1976 AA moved away from the Earth relatively slowly and this made it possible to obtain an unusual number of physical observations during its discovery apparition. It has an albedo of 0.18 and an effective diameter of approximately 900 m. Because of the period of 0.950 years, its position relative to the Earth goes through a cycle of 19 years. After its discovery in January, 1976, it is seen each year a little earlier at an increasing least distance until from 1981 to 1989 it is effectively unobservable on the far side of the Sun, and then in 1995 it will come very close to the Earth again.

1976 UA has an even smaller orbit and a period of only 0.775 years. Just before its discovery in October, 1976 it was only 1.165 million km from the Earth which is three times the distance of the Moon.

At the other end of the scale, 1977 UB was discovered in October, 1977 and proved to be moving so much more slowly than the usual minor planets, that its orbit seemed likely to be well beyond Saturn and almost as far as Uranus. As more observations were obtained over a period of a month or more, a preliminary orbit was calculated. Plates taken in earlier years were searched and images of the planet were found on plates taken in 1941 and even as long ago as 1895. With the help of these positions, quite a good orbit has now been calculated and the planet has a period of 50.7 years. It has a moderately elongated orbit with a mean distance of 13.69 astronomical units (AU) and greatest and least distances of 18.88 AU and 8.51 AU. For comparison the mean distances of Saturn and Uranus are 9.54 AU and 19.18 AU. The largest orbit previously known was that of 944 Hidalgo with a mean distance of 5.8 AU and a period of 14.0 years. 1977 UB has now been allotted a name, it is to be called Chiron. Because it is so far away it must be a fairly sizable body to appear as bright as it is, but because of the uncertainty of its albedo, the best guess we can make is that it probably has a diameter of a few hundred kilometres.

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# Late Quaternary Deposits of the Newcastle-Port Stephens Area as Revealed by Grain Size Analysis and Scanning Electron Microscopy

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ABSTRACT. Modern sediments of the Newcastle-Port Stephens area were examined by grain size analysis and scanning electron microscopy to determine their characteristic differences. Sands from the nearshore marine, beach and frontal ridge, transgressive dune, and river environments are differentiated by their grain size characteristics and surface textures of quartz grains. The differences obtained in the modern environments were applied to the older Quaternary deposits of the area in order to reconstruct their depositional environments. Each Holocene or Pleistocene sequence is composed of relict deposits of nearshore marine, beach, frontal ridge, and river sands.

## INTRODUCTION

Depositional environments of unconsolidated ancient sediments are generally interpreted from either sedimentary structures or fabric in undisturbed cores. When these cores are not available, physical properties of sediments are probably the only sedimentological evidence from which depositional environments can be interpreted. Techniques to differentiate sedimentary environments of modern sands have been developed. Among these techniques grain size analysis and Scanning Electron Microscopy (SEM) appear to have received more attention than the others. Despite the claim made by Shepard & Young (1961) that grain size parameters were of no use in environmental determination,many authors have demonstrated that grain size parameters, particularly skewness, are environmentally sensitive and can be used in determining depositional environments of unconsolidated sediments: (see Mason & Folk, 1958; Friedman, 1961; Duane, 1964; Moiala & Weiser, 1968). At the same time surface textures of quartz sand grains as revealed by SEM have increasingly become a tool to study depositional environments of sands (see Nordstrom & Margolis, 1972; Krinsley & Doornkamp, 1973; Krinsley, Biscaye & Turekian, 1973).

Most of the studies have been concentrated on collecting data from modern environments. Controversy exists on the usefulness of these data when they are applied to older deposits. Chappell (1967) concluded from a sieve analysis with 0.25 phi intervals that beach sands were negatively skewed and dune sands positively skewed with the resolving power of skewness decreasing as the intensity of diagenesis of sediments increased. Hails & Hoyt (1969) sieved the unconsolidated Holocene and Pleistocene sediments of the lower Georgia Coastal Plain at 0.25 phi intervals and found that skewness was environmentally sensitive. Against this, Omara, Bishara & Nasr (1974) who used data from one phi interval sieving, found that grain size parameters as determined by several methods were not successful in allocating the Nubia sandstones of Egypt to certain paleo-environments. Less controversy exists in the use of surface textures of quartz grains to determine depositional environments, although diagenesis has been considered as the main obstacle in the study of ancient sediments (Margolis & Krinsley, 1974).

This paper is an attempt to reconstruct the depositional environments of the late Quaternary deposits of the Newcastle-Port Stephens area. Because of the lack of information on sedimentary structures of the deposits below sea level and because of the existing controversy, two steps were undertaken in the study. First, samples collected from the modern environments (nearshore marine, beach, frontal ridge, transgressive dune and river) were examined by the grain size analysis and SEM to determine characteristic differences. Second, using the same procedures of analysis, relict sediments were analysed and examined, and their depositional environments were inferred from the data obtained from modern environments.

## GEOLOGICAL BACKGROUND

The deposits of the Newcastle-Port Stephens area are the products of marine, eolian and terrestrial processes which have operated during the late Quaternary. The marine-eolian deposits are contained in two sand barriers known as the Inner Barrier and the Outer Barrier. Figure 1 illustrates the positions of these barriers relative to the shoreline. The Inner Barrier which now stands higher than the present sea level is last interglacial in age (Thom, 1965; Roy & Thom, 1975) and composed of beach ridges and longitudinal dunes. A series of subdued beach ridges occurs at the eastern end of the barrier and stands approximately 0.5 - 2 m above swales. Most of the ridges are covered by low vegetation, whereas the swales are mostly wet and contain peat less than one metre thick. The beach ridges have been reworked since the last interglacial into parabolic and longitudinal dunes. The individual dunes 1-2 km in length and up to 30 m high are now stabilized by vegetation.

The Outer Barrier relates to the postglacial transgression and has developed during the last 10,000 years as suggested by numerous radiocarbon dates (Thom, 1974; Sheperd, 1974). It is separated from the Inner Barrier by a swampy inter-barrier depression. Unlike the Inner Barrier, the Outer Barrier shows sharp relief with little modification following dune stabilization by vegetation. Beach ridges occur at the eastern end of the barrier while in the other parts, they have been buried under transgressive dunes.

* communicated by M. Krysko v. Tryst

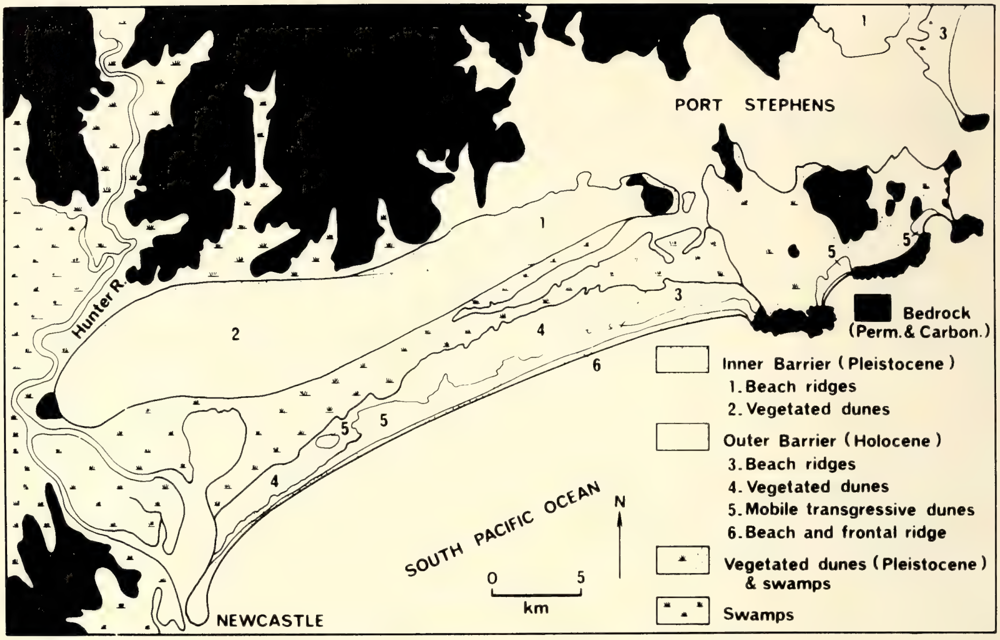


Fig. 1. Map showing surface morphology of the Newcastle-Port Stephens area

The estuarine deposits occur in tidal creeks and flats, which are either represented by deltas such as that of the Hunter River or basins which receive relatively little terrestrial charge. The upper part of the estuarine deposits of the Hunter River are characterized by brackish swamps crossed by tidal creeks. Vegetation plays a part in the geomorphological evolution of the lower part of the estuarine deposits, which is crossed by numerous tidal creeks and covered by scrubs on the low relief mudflats and, where the relief is slightly higher, by mangrove and salt marsh plants. In the sheltered parts of Port Stephens and along the interbarrier depression, tidal processes have lead to the deposition of fine sediments and the development of mudflats with brackish and fresh water swamp deposits. In Port Stephens, the sand transported by nearshore currents and waves is deposited along the estuarine shoreline and form beaches.

In the Hunter river valley which drains into the area, the fluvial deposits are composed of sediments of flood plains and alluvial terraces. The flood plains of the lower Hunter have a gentle undulating relief and are characterized by active and abandoned channels and levees, crevasse splays, flood basins and back-swamps. In the lower reaches of the river, alluvial terraces are composed mainly of sand mixed with silt and clay and occupy most of the valley floors.

Four active sedimentary units have been recognized in the modern open ocean environments of the Outer Barrier: nearshore marine, subaerial beach, frontal ridge, and transgressive dune (Fig. 2). The nearshore marine zone is an active area seaward of the beach to depths of approximately 15 m below mean sea level. The zone is divided into the inner part and the outer part. The inner part (0-10 m) is an active zone, and is characterized by bars and troughs, which are constantly changing their shapes and sizes in adjustment to wave regime. The outer part (greater than 10 m) is characterized by sporadic movements, and possesses a gently inclined slope of varying gradient.

The beach is subjected to periods of erosion interspersed with periods of deposition. A relationship has been observed between mean size of sediment and beach gradient with beach slope tending to be steeper where there is coarser beach material (Ly, 1976). Bedding characteristics are observed in the sand cliffs formed during phases of beach erosion.

The frontal ridge occurs in a morphological zone landward of and parallel to the beach. The ridge is an ephemeral feature subject to periodic destruction by high energy waves. During periods of non-erosion the sand is transported primarily by onshore wind from the beach to accumulate around herbaceous plants. The sedimentary structures include short and steep dipping crossbeds as well as discontinuous low angle dipping laminae.

The mobile transgressive dune includes the free moving sand sheet which covers the areas landward of the frontal ridge. This sheet is seasonably reworked into elongate asymmetrical ridges of the "reversing dune" type. The dune sand is characterised by a combination of steeply and gently dipping laminae associated with leeward and windward slopes respectively. Individual crossbed units attain a thickness of up to 5 m.

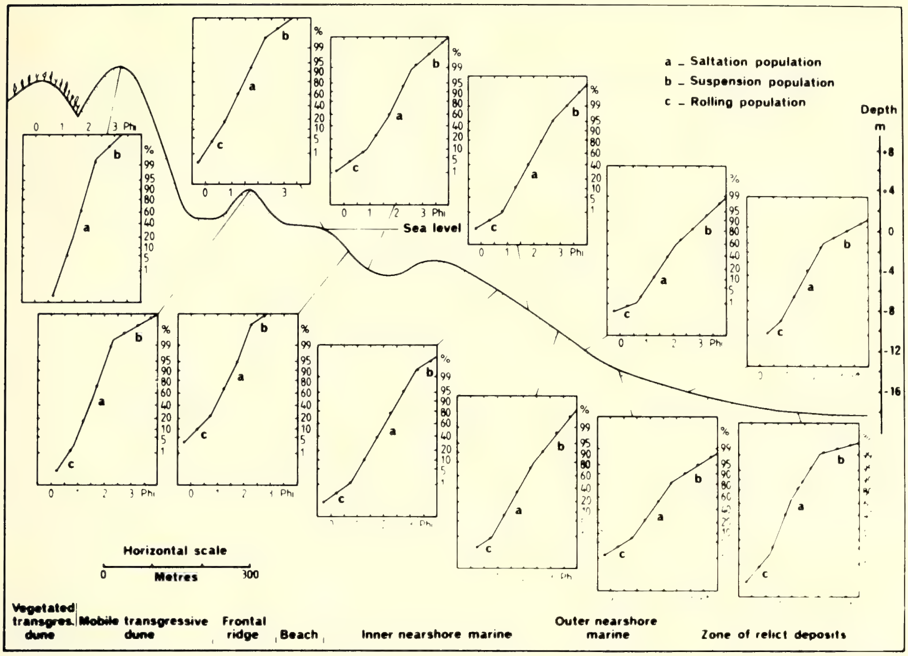


Fig. 2. Grain size distributions of the modern marine sediments of the Newcastle-Port Stephens area

## PROCEDURES

Surface samples from the beach, frontal ridge and transgressive dune were collected by hand, whereas those from the nearshore marine zone were taken by a dredge and by diving. The sub-surface samples were collected by drilling with a power auger. The samples were washed to remove salt and humate. They were then oven dried and sieved at 0.25 phi intervals for 20 minutes on a Ro-tap machine. The weights of the sieved fractions of each sample were converted to weight percentages which were then put into a computer. The programme of Schlee & Webster (1965) was used to compute the four moment parameters (mean, standard deviation, skewness and kurtosis) of each sediment sample.

The procedures used for cleaning quartz sand grains for SEM examination are those described by Krinsley & Doornkamp (1973). With the aid of a binocular microscope between 10 and 15 grains of different external appearance were selected from the cleaned sample and mounted on the SEM sample holder using double-sided adhesive tape. The size of the particles taken for the SEM examination was determined by the grain size distribution of the sample. In the case of unimodal sand, the grains were selected from the 0.25 phi modal range, whereas in the case of polymodal sand, the grains were taken from each of the different modes. The samples were gold coated and viewed with a JEOL-50A scanning electron microscope.

## MODERN SEDIMENTS

### Nearshore marine sand

The nearshore marine sands are quartzose and medium to fine-grained. The sands become finer with increasing depth in the range 0-15 m, below which they tend to be coarser (Fig. 3). These coarse sands, which are similar to the present day beach sands (in size and composition) probably represent the relict beach sand deposited on the continental shelf during a lower sea level stand. Quartz grains are typically angular in the outer zone, whereas sands from the inner zone are composed of rounded to sub-rounded grains. Figure 2 illustrates a typical cross section showing the variations of grain size distribution in the various parts of the open ocean environment. The samples from the outer nearshore zone are characterized by three or four populations: one rolling, one or two saltations and one suspension (see Visher, 1969). Higher amounts of rolling population are usually observed in the inner nearshore zone where they can be up to 20-25% at the bar. In this zone the amounts of suspension population are low and always less than one per cent, whereas in the outer nearshore zone they can reach 20%. The nearshore marine samples are well to moderately sorted. The best sorted samples are transported by saltation. The addition of a coarse rolling population in the bar zone or a fine suspension population in the outer nearshore zone makes the sediments more poorly sorted (Fig. 3). The sign of skewness depends on the relative abundance of the coarser and finer ends of the grain size distribution. In the inner nearshore zone where the coarse population

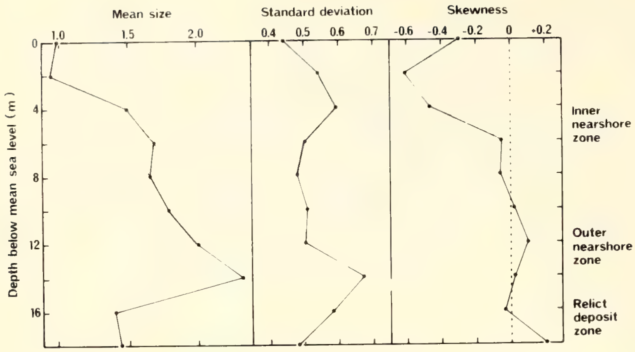


Fig. 3. Variations of grain size parameters in the nearshore marine zone

is higher, the sediments are negatively skewed whereas in the outer nearshore zone where the finer fraction predominates over the coarser end, the sediments become positively skewed. Contents of marine mollusc shells usually vary from 4 to 6% in the inner nearshore zone, but higher amounts up to 10% are often observed in the outer nearshore zone.

The surface textures of quartz sand grains from the nearshore marine environment are characterised by both mechanical and chemical features. In the low energy outer nearshore marine zone, chemical features are predominant and are characterized by various etch cavities (Fig. 4A). Oriented etch forms were observed for the first time by Biederman (1962) in New Jersey and were believed to had been produced during chemical attack by alkaline sea water. The mechanical features composed mainly of v-shaped pits were also observed but their number is minor with less than one pit per $\mu^2$ in the outer nearshore zone. Increase in size and number of mechanical pits was observed on the quartz grains from the more active inner nearshore zone (Fig. 4B).

Beach and frontal ridge sand

The beach sands are quartzose, coarse to fine-grained, and are composed primarily of rounded grains. They are characterized by one or two saltation populations, which are truncated with or without a small suspension population (always less than one per cent). The rolling population usually occurs in the samples from the high energy section of the beach (i.e. western end). The beach sands are usually very well to well sorted (Fig. 5). Higher values of standard deviation are found in the sands from the western end of the beach where a rolling population is found at the coarser end of the size distribution. Approximately 90% of the beach samples showed a negative skewness (Fig. 6), and the remaining samples were either normal or slightly positively skewed. The removal of most of the finer fraction from the size distribution due to winnowing action in the high energy beach zone causes the beach sands to be negatively skewed (Friedman, 1961). Shell content of marine molluscs varies from less than one percent in the areas most exposed to wave action to as high as 30% in protected areas, but is normally in the order of 2-7%.

The frontal ridge sands are medium to fine-grained. They are usually characterized by two saltation populations and a suspension population. In all the samples the saltation population represents about 99% of the distribution. The frontal ridge samples are very well to well sorted. About 80% of the samples analysed were negatively skewed.

In the high energy beach and frontal ridge, the surface textures of quartz sand grains are primarily characterized by mechanical pitting. The most diagnostic features are the v-shaped pits, which are from 0.2 to 3μ in diameter with an average of 0.5μ (Fig. 4C). The pits number on the order of 3-4 pits per $\mu^2$. The presence of these pits on the quartz grains from the beach environment has led to the general belief that they are due to the impact between grains in this turbulent aqueous high energy environment. The exact mechanism however is still not clear, but Margolis & Krinsley (1974) have mentioned the incipient cleavage of quartz as a significant factor. The other mechanical features include straight or curved grooves and conchoidal breakage patterns (Fig. 4D). The grooves can be best seen at magnifications between x1000 and x2000. Their length ranges from a few microns to as much as 15μ. They are found associated with mechanical v-shaped pits, and therefore are considered to be of similar origin by Krinsley & Doorkamp (1973). Conchoidal breakage patterns are usually small (3-5μ in average diameter) and are sometimes observed on the surfaces of beach sand grains. As these features occur only in the high energy beach environment it is possible that they are impact features between sand grains in a turbulent aqueous medium.

Chemical features such as etch cavities can be seen on the quartz grains from the beach and frontal ridge sands. These cavities are irregular in shape, and are usually smaller than those observed in the outer nearshore marine zone.

Dune sand

The mobile transgressive dune is composed of quartzose, medium to fine sand, with rounded to well rounded grains. The sand is characterized by more than 99% of saltation population. The general lack of competence of the onshore wind action to move sand particles by rolling appears to be responsible for the very small percentage or absence of the coarse population. The dune sands are very well sorted

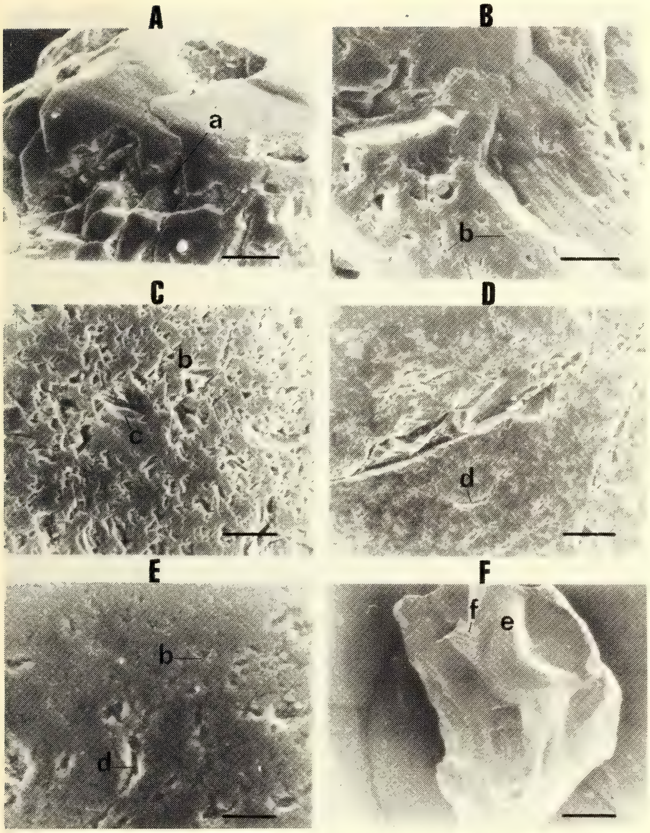


Fig. 4. Scanning electron micrographs of the surface textures of quartz grains from the modern environments of the Newcastle-Port Stephens area. (A) Outer nearshore sand with predominant chemical etching by sea water (a). Scale bar = 10μ. (B) Inner nearshore sand. Mechanical pits (b) are more predominant than chemical features. Scale bar = 25μ. (C) Beach sand with mechanical v-shaped pits (b) and small conchoidal breakage patterns (c). Scale bar = 5μ. (D) Beach sand with mechanical v-shaped pits and curved grooves (d). Scale bar = 10μ. (E) Dune sand with subdued mechanical pits. Scale bar = 10μ. (F) River sand with large conchoidal fractures (e) and imbricated breakage blocks (f). Scale bar = 100μ.

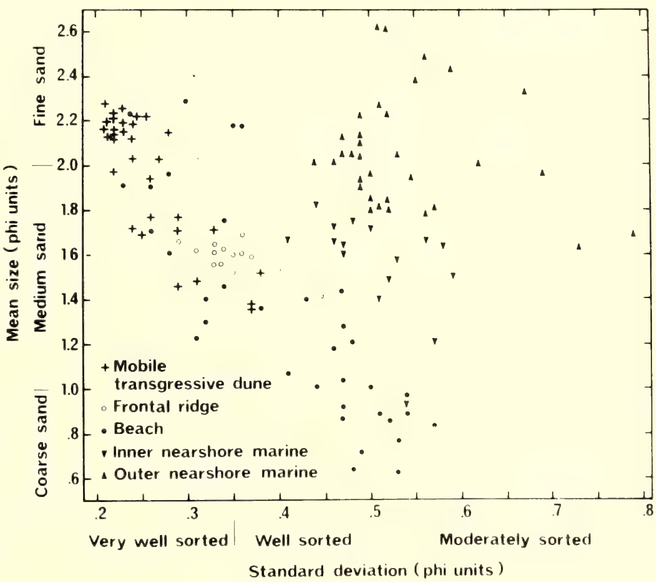


Fig. 5. Scatter plot of mean size against sorting (standard deviation) for samples from the modern environments of the Newcastle-Port Stephens area. Dune sands are always better sorted than nearshore marine sands. Nearshore marine sands are usually finer than beach sands.

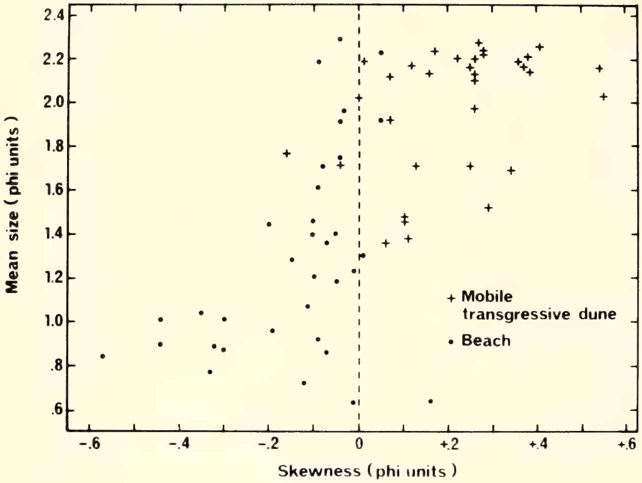


Fig. 6. Dune sands tend to be finer than beach sands. The former are almost always positively skewed whereas the latter are commonly negatively skewed.

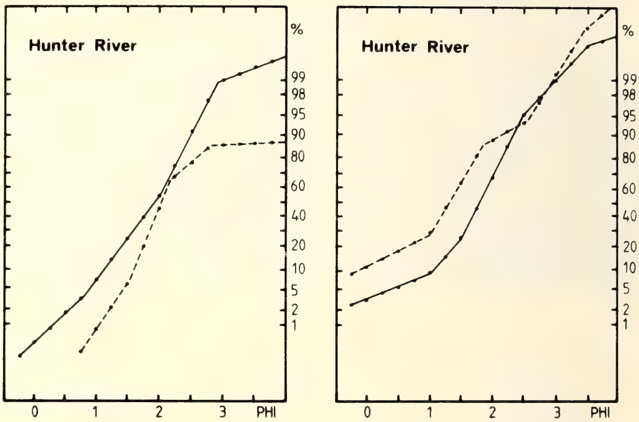


Fig. 7. Grain size distributions of river sands.

(Fig. 5). Out of thirty three samples collected, only two were negatively skewed and one unskewed; the remaining samples were positively skewed (Fig. 6). The dune sands are almost free of shells with a content usually less than 2%.

Mechanical features such as v-shaped pits and straight or curved grooves are still visible on the quartz grains from the mobile transgressive dune (Fig. 4E). At low magnifications, the grains appear very similar to those from the beach zone. However, at higher magnifications (greater than x2000) the mechanical pits are slightly modified by chemical action, and show irregular boundaries.

River sand

Sediments from the lower Hunter River are composed of medium to fine sands mixed with varying amounts of muds. The sand fraction is lithic and composed primarily of angular grains. It is characterized by a suspension population which usually comprises 5 to 10% of the distribution, a poorly sorted saltation population, and a coarse rolling population (Fig. 7).

The diagnostic feature of the river sand is probably the absence of "micro" mechanical or chemical pits. However, these sands are characterized by large conchoidal fractures and imbricated breakage blocks (Fig. 4F). Evidences of mechanical pitting and chemical action have been found superimposed on the above features in the samples from the lower estuary.

RELICT SEDIMENTS

The late Quaternary deposits of the Newcastle-Port Stephens area consist of two sequences: Pleistocene and Holocene (Fig. 8). The lower part of the Pleistocene sequence is composed of clays interbedded with river sand and gravel, and is believed to overlie unconformably the Newcastle Coal Measures of the Permian System (Osborne, 1945). The characteristics of these Pleistocene clays are similar to those of the modern estuarine

muds of the area, and are therefore interpreted as to have been deposited in a sheltered marine environment, i.e. estuarine. These estuarine clays are overlain in most parts by marine sediments of the Inner Barrier, which were deposited during the last interglacial periods (Roy & Thom, 1975). The Inner Barrier is composed of quartzose, coarse to fine sand. Its upper part is strongly affected by podzolization during the last glacial period of low sea level with well developed A horizon of leached grey to white incoherent sand, 0.5 to 4 m thick. This leached sand overlies a dark brown to black humate impregnated sand (average 6-8 m thick), often indurated (B horizon). The presence of humate well below the present sea level suggests that the humate developed during periods of the last glacial lower sea level (Thom, 1965).

The Holocene sequence of the Outer Barrier which is separated from the underlying Pleistocene sequence by a disconformity is composed of quartzose, medium to fine sand. Podzolization is less intense than that observed in the Pleistocene sequence. No indurated sand has been observed in the Holocene sequence.

The processes of podzolization may cause considerable changes of the primary properties of sediments. Figure 9 illustrates that the introduction of humate in sands tends to increase the values of skewness. Standard deviation is less affected by the organic diagenesis than the skewness, whereas the mean size does not change greatly. Therefore, for environmental interpretation, the post depositional humate component had to be removed from the sediments before depositional environments were interpreted.

The elongated, shore-parallel depression between the Inner Barrier and the Outer Barrier was filled by Holocene estuarine mud and sand. The sand fraction is generally less than 50%, and is quartzose with abundance of subrounded to rounded grains similar to marine or dune sand grains. Kaolinite is the main clay mineral in the mud, although minor amounts of illite and montmorillinite are sometimes found. Pyrite is a common authigenic mineral. At the landward side, the deposits of estuarine mud and sand overlie the Pleistocene surface, whereas at the seaward side they grade into the Holocene marine deposits.

Table 1 summarizes the characteristic differences between the modern sediments of the Newcastle-Port Stephens area. When these differences are applied to the sediments of the late Quaternary deposits of the area, several sedimentary units of different depositional environments can be identified (Fig. 10).

Nearshore marine sand

The nearshore marine sand occurs as a tabular unit which occupies the lowest part of each Pleistocene or Holocene sequence (Fig. 10, units A and E). In the Pleistocene sequence, the unit occurs on top of the estuarine clay deposits, and in the Holocene sequence it overlies disconformably the Pleistocene surface of the Inner Barrier or the discontinuous, thin estuarine mud and sand deposits (Fig. 8). The thickness of the unit ranges from 8 to 14 m in each sequence. The unit is usually free of humate and whole shells of molluscs are often encountered. The sand is quartzose, medium to fine-grained, well to moderately sorted, and is composed of rounded to angular grains. In each sequence the outer nearshore marine sand can be distinguished from the inner nearshore marine sand by the grain size and surface textures of the quartz sand grains. The former is finer than the latter. In size distribution the outer nearshore sand usually contains a larger suspension population than the inner nearshore sand, though the difference is sometimes not very great in the Holocene sequence. The nearshore sand tends to be less well sorted with depth in the Pleistocene sequence.

The SEM reveals that quartz grains are characterized by chemical as well as mechanical features. Strong chemical etching is observed in the outer nearshore sand (Fig. 11 A & B) in which etch cavities are large and deep, on the order of several microns in size. The intensity of mechanical pitting decreases with depth. The v-shaped pits are usually of the order of 0.2-0.3$\mu$ in size, and their average number varies from two pits per $\mu^2$ in the inner near-shore sand to less than one pit per $\mu^2$ in the outer nearshore sand.

Beach - frontal ridge sand

In each Pleistocene or Holocene sequence, the inner nearshore sand grades upward to the beach - frontal ridge sand (Fig. 10, units B and F). It occurs as a continuous layer, less than 5 m thick. In the Pleistocene sequence, the upper part of the layer is often affected by humate impregnation and the sand is organically stained and brown in colour. When the sand is free of humate, it is yellow or grey. Shell gragments are often found in the Holocene beach - frontal ridge sand. The beach - frontal ridge sand is quartzose, coarse to medium-grained, well sorted and negatively skewed. It is composed primarily of rounded to subrounded grains.

Although a real boundary does not exist between the inner nearshore marine unit and the overlying beach-frontal ridge unit, the grain size analysis and SEM of quartz grains usually show gradual changes in sediment properties between these two units. The inner nearshore sand (i.e. samples 4 and 5 in the Holocene sequence, and sample 10 in the Pleistocene sequence; Fig. 10) is generally finer-grained and more poorly sorted than the overlying beach sand (samples 2, 3 and 9). The size distribution of this beach-frontal ridge sand is similar to that of the modern beach sand, and is characterized by a rolling, one or two saltation, and usually a small suspension population (Fig.10B and F).

The surface textures of quartz grains from the beach-frontal ridge sand are characterized primarily by mechanical v-shaped pits and less often by straight or curved grooves (Fig. 11, C and D). The number of the pits per $\mu^2$ in this sand tends to be higher than that observed in the underlying nearshore marine sand. The pits with an average size of 0.5$\mu$ vary in number from two to three pits per $\mu^2$ in the Pleistocene sequence, and up to four pits per $\mu^2$ can be seen in the Holocene sequence.

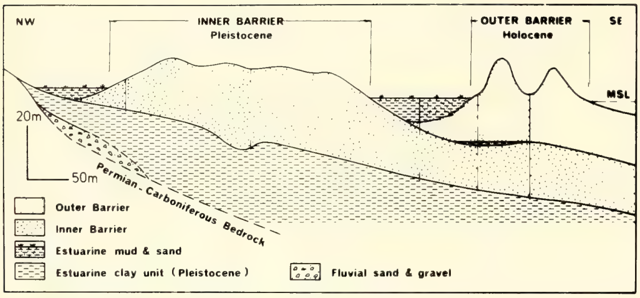


Fig. 8. Cross section of the late Quaternary deposits of the Newcastle-Port Stephens area.

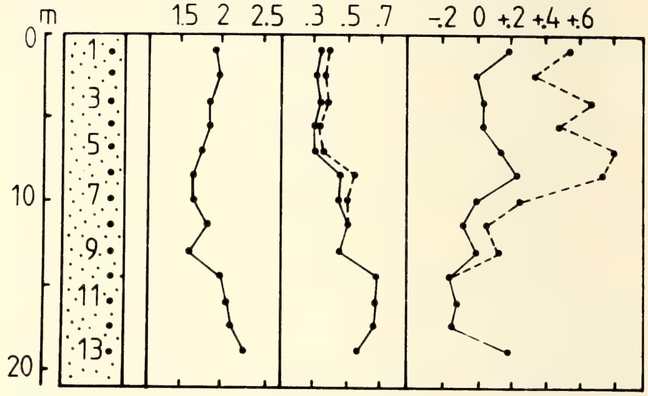


Fig. 9. Changes of sediment properties before and after removal of humate.

Phi units
----------Sediment + humate
________Sediment without humate

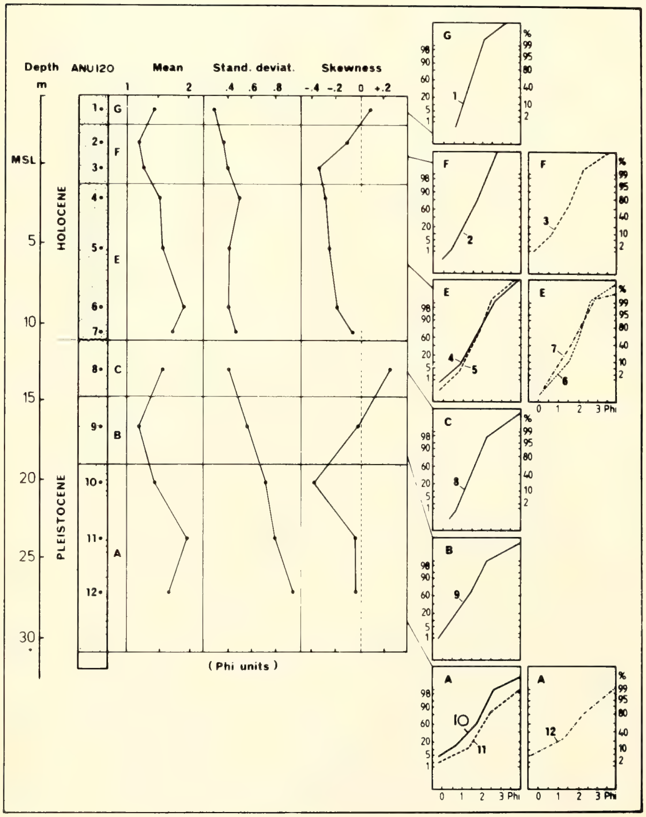


Fig. 10

Sedimentary units of the late Quaternary deposits of the Newcastle-Port Stephens area, as determined from size analysis.

Table 1. Characteristics of the modern sediments of the Newcastle-Port Stephens area

| ENVIRONMENT | TYPICAL MEAN SIZE RANGE | TYPICAL SORTING RANGE | SKEWNESS | SIZE DISTRIBUTION | SEM OF QUARTZ GRAINS |
|---|---|---|---|---|---|
| Dune | Medium to fine sand $M\phi = 1.35\text{-}2.25$ | Very well sorted $\sigma\phi = 0.21\text{-}0.37$ | Usually positive | - A large saltation population<br>- Small suspension and rolling population. | Subdued mechanical pits |
| Beach & frontal ridge | Coarse to medium sand $M\phi = 0.63\text{-}1.90$ | Very well to moderately sorted $\sigma\phi = 0.25\text{-}0.57$ | Usually negative | - A large rolling and a small suspension population.<br>- One or two sub-saltation populations. | Mechanical pits are predominant; v-shaped pits, straight or curved grooves and small conchoidal breakage blocks. |
| Inner near-shore | Medium sand $M\phi = 1.20\text{-}1.80$ | Well to moderately sorted. $\sigma\phi = 0.40\text{-}0.59$ | Often negative | - Similar to beach and frontal ridge sand. | -Mechanical pits (v-shaped pits, and straight or curved grooves).<br>-Solution features (irregularly-shaped etch cavities) |
| Outer near-shore | Medium to fine sand $M\phi = 1.80\text{-}2.60$ | Well to moderately sorted $\sigma\phi = 0.42\text{-}0.79$ | Often positive or unskewed | A small rolling and a large suspension population.<br>-One or two sub-saltation populations | -Solution features are predominant: large and irregularly shaped etch cavities. |
| River | Medium to very fine sand. $M\phi = 1.20\text{-}3.00$ | Usually well to poorly sorted $\sigma\phi = 0.4\text{-}1.20$ | Positive and negative | -A large suspension population.<br>-Two or more sub-saltation populations. | -Large conchoidal fractures and imbricated breakage blocks, and absence of mechanical or chemical "micro" textures. |

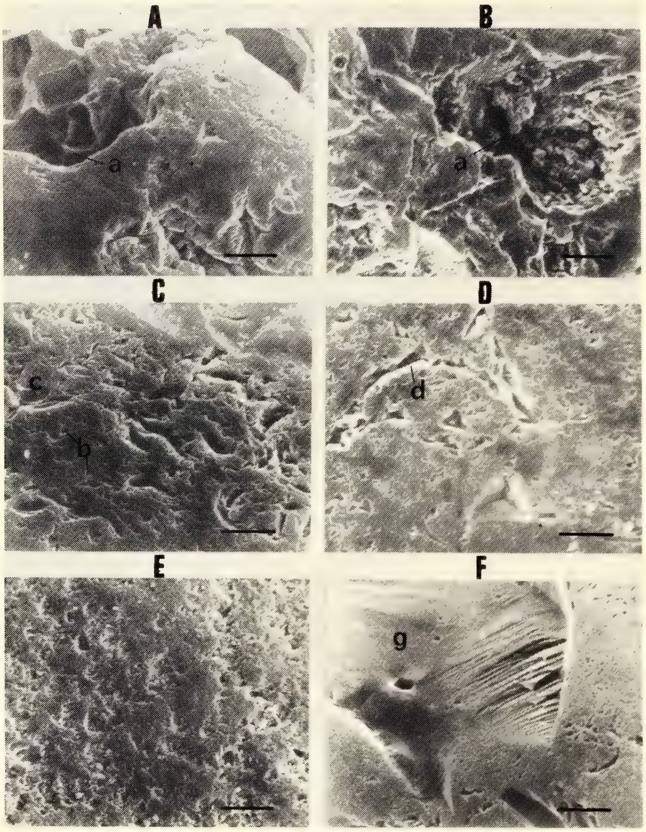


Fig. 11. Scanning electron micrographs of the surface textures of quartz grains from the late Quaternary deposits of the New-castle-Port Stephens area. Nearshore sands are characterized dominantly by etching features (a): (A) Pleistocene sand. Scale bar = 13μ . (B) Holocene sand. Scale bar = 20μ . Beach sands are characterized primarily by mechanical v-shaped pits (b) and curved grooves (d): (C) Pleistocene sand. Scale bar = 5μ ; (D) Holocene sand. Scale bar = 6.5μ . (E) Pleistocene leached sand. Mechanical pits are almost completely removed from the grain surface. Scale bar = 20μ . (F) Pleistocene sand from B Horizon. Precipitation features as smooth surfaces (g) are found associated with mechanical features. Scale bar = 20μ .

Dune sand

Dune sand occurs on top of each sequence and overlies conformably the beach-frontal ridge sand (Fig. 10, units C and G). In the Pleistocene sequence, the sand above sea level represents a continuous unit covered by vegetation, but drilling has revealed that, below sea level, this sand unit becomes discontinuous and thinner (Fig. 12). The dune sand is affected by podzolization with a higher intensity of development in the older Pleistocene sequence. The colour of the sand varies from white or grey in the leached zone to brown or black in the humate deposited zone. In both Pleistocene and Holocene sequences, the sand is completely free of shells.

The sand is quartzose, medium to fine-grained, very well sorted, and is made up of well rounded to rounded grains. It is almost always positively skewed, and is distinguished from the underlying beach sand which is negatively skewed.

The size distribution is often characterized by a single saltation population terminated by a suspension population at the finer end and sometimes by a small rolling population at the coarser end (Fig. 10, C and G).

Differences in surface textures of quartz grains have been observed in the soil profile of each sequence. In the leached zones, the mechanical features are almost completely removed by the solution-precipitation action during podzolization (Fig. 11E). In the zones of deposition, the solution-precipitation features occur together with the subdued mechanical v-shaped pits and straight or curved grooves (Fig. 11F).

Backbarrier sand

In addition to the relict sands of the nearshore marine, beach-frontal ridge, and dune deposits, the so-called backbarrier deposits have also been recognized (Fig. 12). These deposits occur behind the Outer Barrier as an elongated, shore parallel, sand body and are characterized by similar properties to those of the open ocean beach and dune deposits, but are differentiated from the latter by the occurrence of usually 1-2% silt and clay. They thin landward and grade into estuarine deposits. The deposits which have deposited in shallow water, or intertidally behind a low relief barrier by washover and aeolian processes, are no longer active.

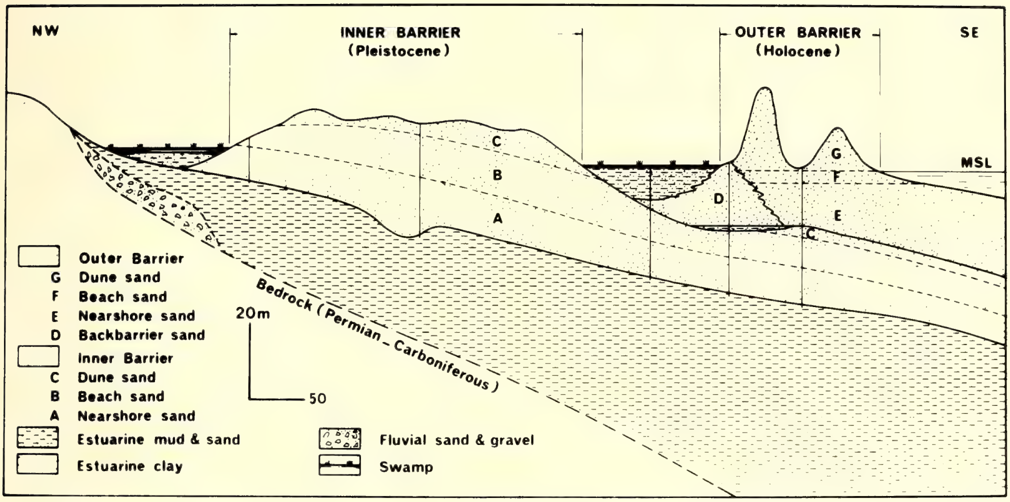


Fig. 12. Generalized cross-section showing the sedimentary units of the late Quaternary deposits of the Newcastle-Port Stephens area.

## CONCLUSIONS

The following conclusions may be summarized from the study:

1) Grain size analysis of the modern sands from the Newcastle-Port Stephens area reveals that mean size, sorting and skewness are environmentally sensitive. Ninety per cent of beach sand samples are negatively skewed and more than ninety per cent of dune sand samples are positively skewed or unskewed. Frontal ridge sands are usually negatively skewed and cannot be differentiated from beach sands. Inner nearshore marine sands are usually finer and tend to be more poorly sorted than beach sands. Outer nearshore marine sands are finer than inner nearshore marine sands.

2) Modern sands are also differentiated by the grain surface features of quartz. Mechanical v-shaped pits are the most diagnostic features of the beach, frontal ridge and inner nearshore marine sands. Solution features are predominant in the outer nearshore marine sands. In dune sands, mechanical pits are subdued by solution-precipitation of silica.

3) The application of data obtained from the modern depositional environments of the Newcastle-Port Stephens area reveals that each Holocene or Pleistocene sequence of the area is predominantly regressive, and is usually composed of three distinct units. A nearshore marine sand occurs at the base of each sequence. It is overlain by a coarser and better sorted beach and frontal ridge sand. The latter is in turn overlain by a finer and better sorted dune sand.

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# Regional-Scale Thermal Metamorphism Overprinting Low-Grade Regional Metamorphism, Coffs Harbour Block, Northern New South Wales

RUSSELL J. KORSCH

ABSTRACT. Two regional metamorphic events are recognised in the rocks of the Coffs Harbour Block in northeastern New South Wales. The first event (M1) is a progressive low-grade regional event with metamorphic recrystallisation increasing southwards towards the Bellinger Fault. In the southern part of the block M1 has been overprinted on a regional scale by a static thermal event (M2). Four metamorphic zones are recognised. Zones I and II contain rocks affected by M1 only, whereas zones III and IV contain rocks affected by both M1 and M2. The sequence of facies produced by M1 is indicative of low-pressure II facies series, whereas the M2 facies belongs to the low-pressure I facies series. M1 is considered to be a part of paired metamorphic belts recognised in New England. M2 is post tectonic and possibly related to the intrusion of post tectonic batholiths.

## INTRODUCTION

The Coffs Harbour Block in northeastern New South Wales comprises a thick sequence of greywackes, siltstones, mudstones and massive argillites. These rocks are considered to be Late Palaeozoic in age (Korsch, 1971). They have been divided into three stratigraphic units by Leitch *et al.* (1971), namely the Moombil Beds, Brooklana Beds and Coramba Beds. The degree of metamorphic recrystallisation in the block increases southwards towards the Bellinger Fault, as does the intensity of deformation of the rocks (Korsch, 1973). The metamorphism is a part of a low-grade regional metamorphism principally associated with a Permian orogeny occurring over a wide area of New England and reported by McKee and Leitch (1971). In this paper the details of the metamorphic history of these rocks are deduced from the relationships of metamorphic minerals to structural elements, and textural relationships of coexisting minerals. Using these features, two major metamorphic episodes have been recognised in the Coffs Harbour Block.

Incipient to low-grade regional metamorphism produced prehnite-pumpellyite facies to lower greenschist facies in the rocks, and this has been overprinted in the southern part of the block by the results of a regional-scale thermal event which produced randomly-oriented biotite grains similar to those observed in contact metamorphic aureoles. Contact metamorphic aureoles also occur around the granitic intrusions but this paper will concentrate on the low-grade regional metamorphism (M1), and the regional-scale thermal metamorphism (M2) which occurs over an area of approximately 2500 $km^2$ (Fig. 1).

## PETROGRAPHY

The metaclastic lithologies show a wide variation in the degree of textural reconstitution but, because of the paucity of metabasic rocks in the sequence, no really diagnostic minerals are developed. Hence it is difficult to demonstrate that an increase in metamorphic grade closely accompanies textural reconstitution. The coarser fraction of the psammites shows little microscopic evidence of deformation or recrystallisation, the lower boundary of metamorphism being indicated mainly by the presence of a finely divided mixture of granoblastic quartz and albite, small granules of epidote, thin threads of chlorite and white mica and rare opaque minerals.

At the lowest grade there is no distinct preferred orientation of the new mineral phases. Veins consisting of variable combinations of quartz, albite, chlorite, prehnite, calcite and epidote have formed in many rocks. Also at the lowest grade, detrital grains are little modified, with restricted albitisation of plagioclase, development of minor epidote, hornblende partly altered to chlorite and some volcanic lithic fragments devitrified to fine-grained granoblastic quartz and feldspar. The detrital grain boundaries still retain their original sharp outlines. Prehnite occurs both as a vein mineral and as a spongy aggregate in the matrix. Pumpellyite is confined to the matrix as tiny randomly-oriented grains usually associated with epidote which appears to have developed as a reaction corona. Chlorite is commonly associated with both prehnite and pumpellyite.

With increasing grade the micaceous groundmass becomes coarser and starts to develop a noticeable preferred orientation, and prehnite and pumpellyite are lacking. Granular phases such as epidote become coarser in the matrix. The coarse detrital fragments develop a dimensional orientation parallel to the preferred orientation of white mica but still show little marginal alteration. Much of the lithic debris is converted to a granoblastic quartz-feldspar aggregate obliterating many of the relict volcanic textures. Mudstone fragments tend to develop minute flakes of white mica.

With further increase in grade some of the textures are masked by the overprinting of thermal biotite and associated minerals. The low-grade regional features appear to be defined by the modification of detrital grain boundaries with both albitised plagioclase and quartz being embayed and fine-grained aggregates developing at the margins.

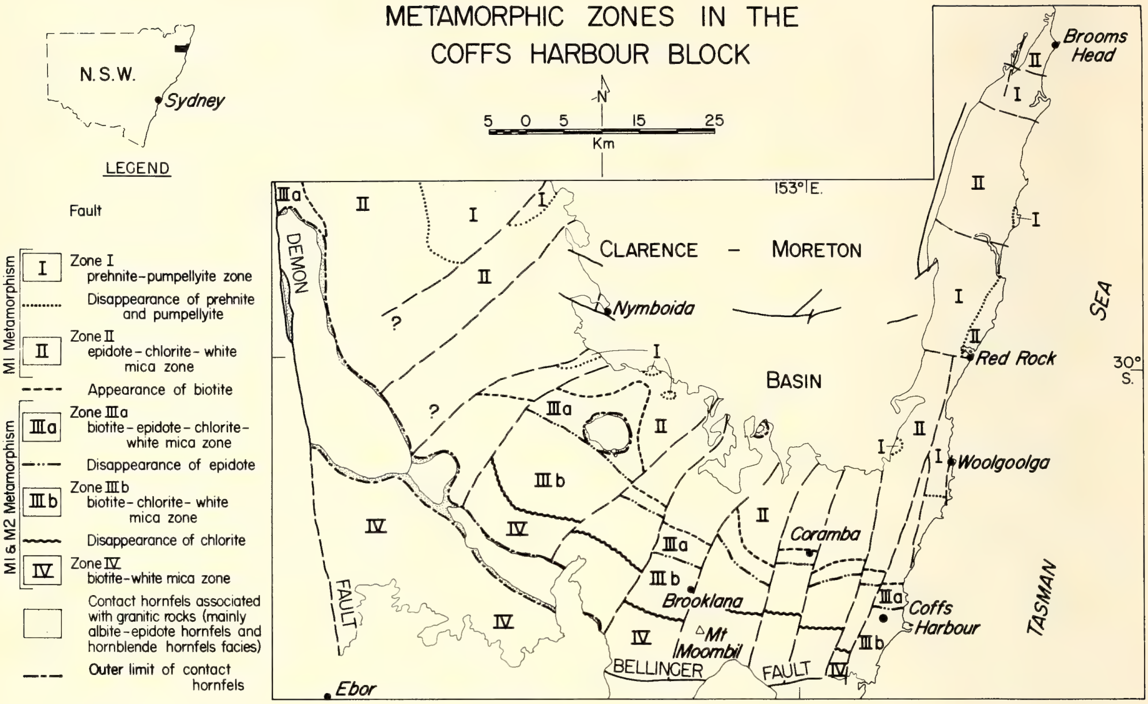


Fig. 1. Metamorphic zones recognised in the Coffs Harbour Block, and the isograds defining zone boundaries.

The rocks consist of relict detrital fragments "floating" in a quartz-albite rich metamorphic "groundmass" with an average grainsize of about 0.03 mm. White mica flakes have become much coarser and show a strong preferred orientation which occasionally swirls around the relict grains. Detrital quartz grains are breaking down to granoblastic aggregates of finer crystals.

The coarsening of groundmass phases, and continued modification of detrital grains with preferential destruction of plagioclase detritus, are indicative of the highest grades observed in the psammitic rocks. Complete textural reconstitution of the rock does not occur and it is still possible to observe some remains of a relict sandstone texture.

Pelitic rocks have been reconstituted mainly to micaceous phases and they resemble the matrix of the psammites. With increasing metamorphic grade these rocks show a textural progression from laminated mudstones to cleaved rocks. In the least affected pelites some flattening may have occurred and a weak foliation may be present. With increase in grade a network of lepidoblastic white mica crystals shows a well developed foliation occasionally overprinted by spongy aggregates of xenoblastic calcite. The white micas completely enclose the small relict detrital quartz fragments which now show a marked dimensional orientation. The highest grade observed in the pelites is the development of a foliation due to the segregation of minerals into bands of quartzo-feldspathic layers and this has involved the almost complete reconstitution of detrital material.

Biotite appears in both pelitic rocks and in the matrix of psammites at approximately the same grade. In pelites it consists of randomly oriented single grains and small clusters of lepidoblastic crystals. In psammites biotite occurs as large clusters (up to 2 mm) of numerous small randomly oriented flakes in the matrix and is located preferentially at boundaries between detrital grains and the matrix. At this early stage there is some breakdown of the margins of detrital grains, particularly of quartz.

The biotite rapidly becomes a major component of the matrix of the psammites and the remainder consists of granoblastic quartz and feldspar with some chlorite, epidote and white mica. At the highest grades biotite is accompanied by large grains of muscovite. This muscovite differs from the white mica produced by the earlier low-grade regional event in that it has a platy rather than acicular form, it does not have a preferred orientation but is randomly oriented, and it is occasionally observed overprinting the M1 white mica.

In many higher grade rocks a foliation produced by the alignment of white mica is still present but has been overprinted by randomly oriented biotite grains which tend to grow

preferentially around boundaries of any grains that have not been reconstituted into the granoblastic groundmass. In some thin sections spongy blebs of calcite developing simultaneously with the biotite, grew across the white mica foliation. Only in rocks of fine-grained parentage has the reconstitution been almost complete and here the biotite often occurs as stringers, presumably being controlled by the bands of parent mineral(s) from which the biotite is growing.

Biotite occurs in all lithological types but is more abundant in pelitic than psammitic rocks. White (1964) described stilpnomelane from the Brisbane Metamorphics which had previously been identified as biotite. Several authors (e.g. Iwasaki, 1963; Brown, 1967; Leitch, 1975) have described stilpnomelane from rocks of similar metamorphic grade to the Coffs Harbour Block. Because of this several samples were crushed and the brown mica separated to a concentrate which was X-rayed in an attempt to distinguish between stilpnomelane and biotite. All samples examined showed a strong 10°A peak indicating the presence of biotite (N = 15, mean = 10.26°A, S.D. = 0.09). Stilpnomelane was not observed in any specimen from the Coffs Harbour Block.

The metamorphic mineral assemblages and their observed distribution in the zonal scheme (see later) are shown in Table 1. Restriction of assemblages to certain zones does not necessarily imply that they are critical to the recognition of that zone. Restriction of a number of these assemblages (e.g. 18, 19, 23, 32) to one zone might be a result of incomplete sampling and some assemblages can be expected to range over several zones.

## M1 AND M2 METAMORPHISM

The first major metamorphic episode (M1) produced low-grade regional effects throughout the whole of the Coffs Harbour Block. This episode coincided with a regional deformation which mainly produced mesoscopic folding and an axial plane cleavage. At higher grades of M1 the alignment of white mica defines a foliation which is parallel to the axial plane cleavage.

The lower-grade parts of the block have been affected only by M1. The products of M1 are not typical in that two diagnostic minerals (actinolite and stilpnomelane) in rocks presumed to be of similar grade of metamorphism elsewhere have not developed in the Coffs Harbour area.

The effects of M2 occur in the southern part of the Coffs Harbour Block and are marked by the development and growth of randomly-oriented biotite and, less commonly, white mica. These micas occur as fine cross-cutting porphyroblasts overprinting the earlier aligned white micas of M1. M2 has only affected the higher-grade rocks of the M1 episode.

## M1 AND M2 METAMORPHIC ZONES

The overprinting by thermal biotite and associated minerals has masked, to a considerable extent, the minerals and textures produced by M1. Recognition of mineral zonations in these rocks is also hampered because mineral phases with restricted stability are not developed to any great extent, probably because of the extremely limited occurrence of suitable lithologies, such as metabasic rocks. Nevertheless, it has been possible to divide the rocks of the block into four mineralogical zones of metamorphism (Fig. 1). In order of increasing grade these are:

Zone I: prehnite-pumpellyite
Zone II: epidote-chlorite-white mica
Zone IIIa: biotite-epidote-chlorite-white mica
Zone IIIb: biotite-chlorite-white mica
Zone IV: biotite-white mica.

Zones I and II contain rocks affected by M1 only, whereas zones III and IV contain rocks affected by both M1 and M2.

Critical assemblages in zone I all include prehnite or pumpellyite or both (Table 1, Fig. 2). This zone is developed only in the northern part of the block. Zone II is a transitional zone lacking diagnostic minerals such as prehnite and pumpellyite. Epidote, chlorite and white mica are the main metamorphic minerals present. The incoming of biotite heralds the start of zone III and this isograd marks the most northerly extent of M2 overprinting M1. This zone is subdivided tentatively into two subzones. In subzone IIIa epidote, chlorite and white mica are all present along with randomly oriented biotite blebs. Subzone IIIb differs from subzone IIIa in that epidote is lacking. In zone IV chlorite is absent and definitive assemblages contain only biotite and white mica as diagnostic minerals.

Zone boundaries used to construct the above zones are defined by (i) the disappearance of prehnite and pumpellyite, (ii) the incoming of biotite, (iii) the disappearance of chlorite. Sampling problems over the Coffs Harbour Block (approximately 5000 $km^2$) and the absence of critical assemblages in some rocks have made accurate mapping of zone boundaries difficult, and in some places they have been inferred.

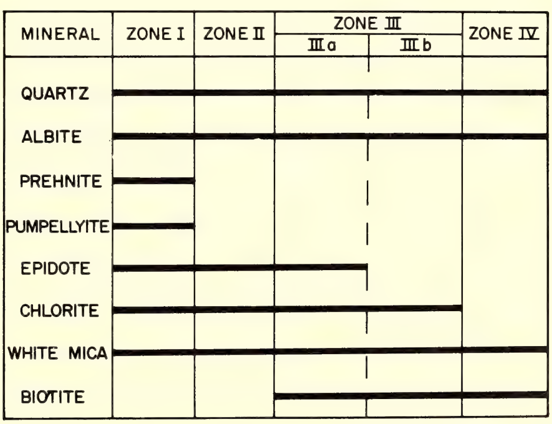


Fig. 2. Zonal distribution of main metamorphic mineral phases in metaclastic rocks from the Coffs Harbour Block.

TABLE 1
METAMORPHIC ASSEMBLAGES IN THE METASEDIMENTARY ROCKS OF THE COFFS HARBOUR BLOCK

| | Assemblage | Zone I | II | IIIa | IIIb | IV |
|---|---|---|---|---|---|---|
| 1. | quartz-albite-prehnite-calcite-(±chlorite or epidote) | X | | | | |
| 2. | quartz-albite-chlorite-epidote-prehnite-(±calcite) | X | | | | |
| 3. | quartz-albite-chlorite-epidote-white mica-prehnite-(±calcite) | X | | | | |
| 4. | quartz-albite-white mica-prehnite | X | | | | |
| 5. | quartz-albite-chlorite-epidote-prehnite-pumpellyite | X | | | | |
| 6. | quartz-albite-epidote-pumpellyite-(±chlorite) | X | | | | |
| 7. | quartz-albite-chlorite-epidote-white mica-pumpellyite-(±calcite) | X | | | | |
| 8. | quartz-albite-chlorite | X | X | | X | |
| 9. | quartz-albite-chlorite-epidote-(±white mica) | X | X | X | | |
| 10. | quartz-albite-chlorite-white mica | X | X | X | X | |
| 11. | quartz-albite-chlorite-epidote-calcite | X | X | | | |
| 12. | quartz-albite-chlorite-epidote-white mica-calcite | X | X | X | | |
| 13. | quartz-albite-chlorite-white mica-calcite-opaques | X | | X | | |
| 14. | quartz-albite-white mica | X | X | X | X | X |
| 15. | quartz-albite-chlorite-epidote-actinolite-(±calcite) | | X | | | |
| 16. | quartz-albite-chlorite-epidote-(±white mica) | | X | | | |
| 17. | quartz-albite-chlorite-epidote-tourmaline | | X | | | |
| 18. | quartz-albite-chlorite-calcite-(±epidote) | | X | | | |
| 19. | quartz-albite-epidote | | X | | | |
| 20. | quartz-albite-epidote-white mica-(±tourmaline) | | X | | | |
| 21. | quartz-albite-chlorite-white mica-calcite | | X | X | X | |
| 22. | quartz-albite-white mica-calcite | | X | X | X | X |
| 23. | quartz-albite-chlorite-biotite-(±epidote) | | | X | | |
| 24. | quartz-albite-chlorite-epidote-white mica-biotite-(±tourmaline) | | | X | | |
| 25. | quartz-albite-chlorite-epidote-calcite-biotite-(±white mica) | | | X | | |
| 26. | quartz-albite-epidote-biotite-sphene-(±chlorite) | | | X | | |
| 27. | quartz-albite-chlorite-white mica-biotite-sphene | | | X | | |
| 28. | quartz-albite-epidote-biotite-(±white mica and/or calcite) | | | X | | |
| 29. | quartz-albite-biotite | | | X | X | X |
| 30. | quartz-albite-chlorite-white mica-biotite | | | X | X | |
| 31. | quartz-albite-white mica-biotite-(±calcite) | | | X | X | X |
| 32. | quartz-albite-chlorite-white mica-calcite-biotite | | | | X | |
| 33. | quartz-albite-white mica-biotite-garnet | | | | X | |
| 34. | quartz-albite-chlorite-white mica-garnet | | | | X | |

The disappearance of prehnite at a stage within the prehnite-pumpellyite facies, and the disappearance of pumpellyite at the upper boundary of the facies, have been recorded in the Sanbagawa Schists (Seki *et al.*, 1971), in the Otago Schists (Bishop, 1972) and in the Nambucca Slate Belt (Leitch, 1975). Other workers (Seki *et al.*, 1969, in the Tanzawa Mountains; Smith, 1969, in the Lachlan Geosyncline) have recorded the disappearance of prehnite and pumpellyite simultaneously. With more detailed sampling in parts of the Coffs Harbour Block it may be possible to recognise two isograds, one marking the disappearance of prehnite, and the other marking the disappearance of pumpellyite. However, because the psammitic rocks on either side of the prehnite-pumpellyite isograd appear to be of similar composition, it is inferred that the disappearance of the two minerals is controlled by metamorphic grade.

Biotite produced by M2 appears to develop in both the matrix of psammitic rocks and in pelitic rocks at approximately the same place and hence appears to be grade dependent with little lithological influence. By contrast, Mather (1970) found that in greywackes in Dalradian rocks biotite developed at a lower grade than in pelites, and therefore in that region it apparently is chemically controlled as well as grade dependent.

The disappearance of chlorite after the disappearance of epidote in the Coffs Harbour Block contradicts most recorded assemblages. James (1955) inferred, however, that biotite probably forms from chlorite because the amount of biotite increases as the amount of chlorite decreases. Hence the disappearance of chlorite at the zone IV boundary is thought to be a grade-dependent event but the possibility of lithological dependence cannot be overlooked.

The disappearance of epidote within zone III deserves comment. The subdivision of zone III into two subzones is based on the absence of epidote in the higher-grade subzone. This situation is unusual because in many metamorphic terrains epidote exists at higher grades after the disappearance of chlorite (Miyashiro, 1958, in Abukuma Plateau; Banno, 1964, in Sanbagawa Schists; James, 1955, in Michigan; Seki, 1957, in Arisu contact aureole, Kitakami Mountains). However the converse, described here, has also been noted by Seki *et al.* (1969) in the Tanzawa Mountains. The more frequent development of epidote and chlorite in psammitic rocks than in pelitic rocks of the Coramba Beds shows that the development of those minerals is controlled by lithology to a certain extent (Fig. 3). The Coramba Beds, which occur in the northern part of the block, were examined closely in a large number of samples (432) partly because of the virtual absence of the effects of M2 overprinting M1. The development of epidote is concentrated in psammitic rocks, occurring in 82% of them but in

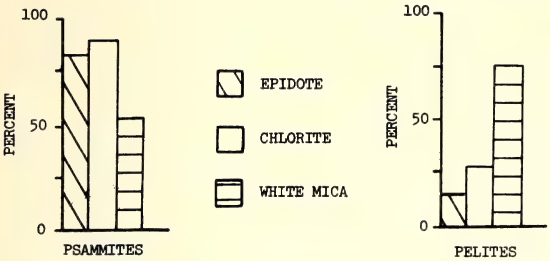


Fig. 3. Development of metamorphic minerals in psammitic and pelitic lithologies from the Coramba Beds.

only 15% of the pelites. The disappearance of epidote at the subzone boundary can be related to the parent lithologies in the three formations. Korsch (1978) has shown that a progressive coarsening of the grainsize of the sediments occurs from south to north. Psammitic lithologies dominate in the Coramba Beds but constitute only 12% of the Moombil Beds, which occur in the southern part of the block. Hence epidote, which is lithologically confined to mainly psammitic rocks, would be rare in the pelite-dominated Brooklana Beds and Moombil Beds. Therefore the subzone boundary is probably controlled by lithology with little or no dependence on metamorphic grade.

### Metamorphic Facies

The presence of prehnite and pumpellyite and the absence of zeolites and actinolite place the rocks of zone I in the prehnite-pumpellyite facies of Coombs (1961).

The absence of both prehnite and pumpellyite in rocks of similar composition to those of zone I suggests that rocks of zone II do not belong to the prehnite-pumpellyite facies. The typical assemblage of quartz-albite-chlorite-epidote-white mica indicates that the rocks occur in the lowest part of the greenschist facies below the biotite isograd. Actinolite is not developed and pumpellyite is lacking as well as prehnite. Hence the transitional pumpellyite-actinolite facies of Hashimoto (1966) is considered to be absent. It is possible that the pumpellyite-actinolite facies was not recognised because of the absence of metabasic lithologies in which actinolite commonly develops. However, Seki *et al.* (1969) and Coombs *et al.* (1970) both consider the pumpellyite-actinolite facies to be suppressed in areas of low-pressure - high geothermal gradient conditions and this has been confirmed experimentally by Nitsch (1971) and Liou (1971).

The incoming of biotite overprinting the previously developed white mica foliation presents a problem of assigning the rocks of zone III to a facies. As far as can be determined all rocks of zones III and IV were metamorphosed by M1 to lowest greenschist facies. The presence of biotite is indicative of either upper greenschist facies or albite-epidote hornfels facies (Turner, 1968). The regional scale of this metamorphic event weighs against inclusion in the albite-epidote hornfels facies and it is preferred to place M2 in the low-pressure greenschist facies of Miyashiro (1973a).

Rocks of zone IV are similar to zone III and have suffered greenschist facies regional metamorphism (M1) which was later overprinted by a regional-scale thermal metamorphism (M2) of low-pressure greenschist facies grade.

The concept of facies series introduced by Miyashiro (1961) and extended by Seki (1969) can be applied to rocks of the Coffs Harbour Block. The sequence of facies produced by M1 of prehnite-pumpellyite to greenschist, with the absence of pumpellyite-actinolite is indicative of low pressure II facies series of Miyashiro (1973a, p. 298) and may be compared with the Tanzawa Mountains (Seki *et al.*, 1969).

The M2 metamorphism of low-pressure greenschist facies belongs to the low-pressure I facies series of Miyashiro (1973a) and may be compared with the rocks from the Iritono area of the central Abukuma Plateau (Shido, 1958).

## CONTACT METAMORPHISM

Contact metamorphic aureoles occur around most of the granitic intrusions in the Coffs Harbour Block. The grade of metamorphism varies from albite-epidote hornfels facies to hornblende-hornfels facies of Turner (1968). Pyroxene-hornfels facies has not been recognised in the area. The albite-epidote hornfels facies is difficult to distinguish particularly in the southern part where thermally-produced biotite has developed on a regional scale. Albite-epidote hornfels facies has been described previously in incompletely reconstituted sediments near the margins of the Emerald Beach Leucoadamellite by Korsch (1971).

Contact zones around the plutons (Fig. 1) define the limits of reconstitution of sediments into hornfels and do not represent the lower boundary of the hornblende-hornfels facies. The typical mineral assemblage observed in completely reconstituted hornfels is quartz-albite-biotite-muscovite-(opaques)-(cordierite)-(garnet).

## DISCUSSION

M1 appears to have been caused by rapid accumulation of the "geosynclinal pile", which caused a rapid increase in $P_{H_2O}$ accompanied by a high geothermal gradient. The alignment of minerals might be attributed to a directed pressure present during deformation. For the conditions of metamorphism for M1, a geothermal gradient of 40°C/km is consistent with the conclusion that M1 is a low pressure facies series, but would be inconsistent if the metamorphism was of medium pressure similar to that described by Leitch (1975) for the Nambucca Slate Belt, and Bishop (1972) from Otago. Both these authors require a geothermal gradient of 15°C - 25°C/km to produce their metamorphic assemblages.

M2 is a product of a regional-scale static thermal event, which is probably post-tectonic in origin. The new metamorphic minerals developed in an area of low confining pressure and high heat flow. It is possible that the heat flow was from a large concealed batholith but there is no real

evidence for or against this suggestion. The age of the thermal event is not known but is assumed to be Late Palaeozoic. M2 has not affected the Nambucca Slate Belt and other regions to the south, which suggests that it was not an accompaniment of the Mesozoic rifting of the Lord Howe Rise from Australia and the formation of a spreading ridge in the Tasman Sea. It is possible that the extensive belt of biotite-grade rocks (up to 40 km wide) may be due to a subhorizontal biotite isograd produced by a subsurface source of heat such as an extensive, continuous concealed batholith.

Age of Metamorphism and Relation to Deformation

In the southern part of the Coffs Harbour Block the slaty cleavage results, in part, from the preferred orientation of metamorphic phases, particularly white mica. Consequently there is a close temporal relationship between M1 and D1 episode of deformation. M2 is post-tectonic, occurring as a static thermal event producing randomly oriented biotite after the directed pressure of D1 had been removed.

There is evidence that, although most of the metamorphic phases occurred during and after D1, crystallisation extended over a longer period. Quartz veins varying in age from pre-M1 to post-M2 have been recognised. It is considered that M1 is contemporaneous with the metamorphism in the Wongwibinda Complex (Binns, 1966) and the Nambucca Slate Belt (Leitch, 1975) and hence is probably Middle Permian in age. Leitch and McDougall (in Leitch, 1978) has determined an age of 250 m.y. for the metamorphism in the Nambucca Slate Belt. M2 is possibly associated with the intrusion of the New England Batholith in Late Permian time.

Tectonic Implications of M1

The metamorphosed sediments of the Coffs Harbour Block are considered to be a part of paired metamorphic belts, consisting of a low-pressure belt and an intermediate-pressure belt, which are recognised in the New England region (Fig. 4). The arcuate belt of low-pressure metamorphism extends from the Coffs Harbour Block through the Wongwibinda Complex (Binns, 1966) to the Tia Complex (Gunthorpe, 1970). A parallel belt of intermediate-pressure metamorphism extends from the Bellinger-Macleay region (Leitch, 1975) to the Warnes River district (Fisher, 1969). These arcuate belts are restricted in extent and are remnants of formerly more extensive, linear features.

Radiometric ages listed by Binns (1966) indicate that the low-pressure metamorphic rocks at Wongwibinda developed during the Permian, and geological evidence cited by Leitch (1974) supports a Permian age for the intermediate-pressure metamorphic rocks in the Bellinger-Macleay region.

Miyashiro (1973b) recognised the tectonic significance of paired metamorphic belts. He showed that low-pressure metamorphic rocks represent zones of ancient volcanic chains or magmatic arcs where high heat flow regimes accompanied the rise of granitic magma, and that high-pressure metamorphic belts represent ancient subduction zones along trenches. Miyashiro also made the significant observation that Palaeozoic high-pressure belts are rare, being represented by intermediate-pressure metamorphic belts, possibly because the rate of plate descent was slower in the Palaeozoic than in later geological time. The low-pressure metamorphic belt, and an associated magmatic arc in which there was both volcanism and plutonism, were above the inferred Benioff Zone.

The volcanics are preserved as extensive remnants on the tablelands north of Armidale (Fig. 4) and have calc-alkaline continental-margin affinities (Langham, 1973). The granitic rocks are more complex, and have been divided into four suites by Korsch (1977). Both the Hillgrove and New England suites are postulated to have formed as a result operating in and above the palaeo-Benioff Zone. Radiometric dates (Fig. 4), taken from the literature, show that the Hillgrove suite is older than most of the New England Batholith, and that the plutons of the New England Batholith in general become younger northwestwards from the Wollomombi plate boundary. The youngest are the Mole and Gilgai granites which are highly acid, potassic and tin-bearing. Hence the metamorphic belts can be attributed to processes operating on opposite sides of a Permian plate boundary.

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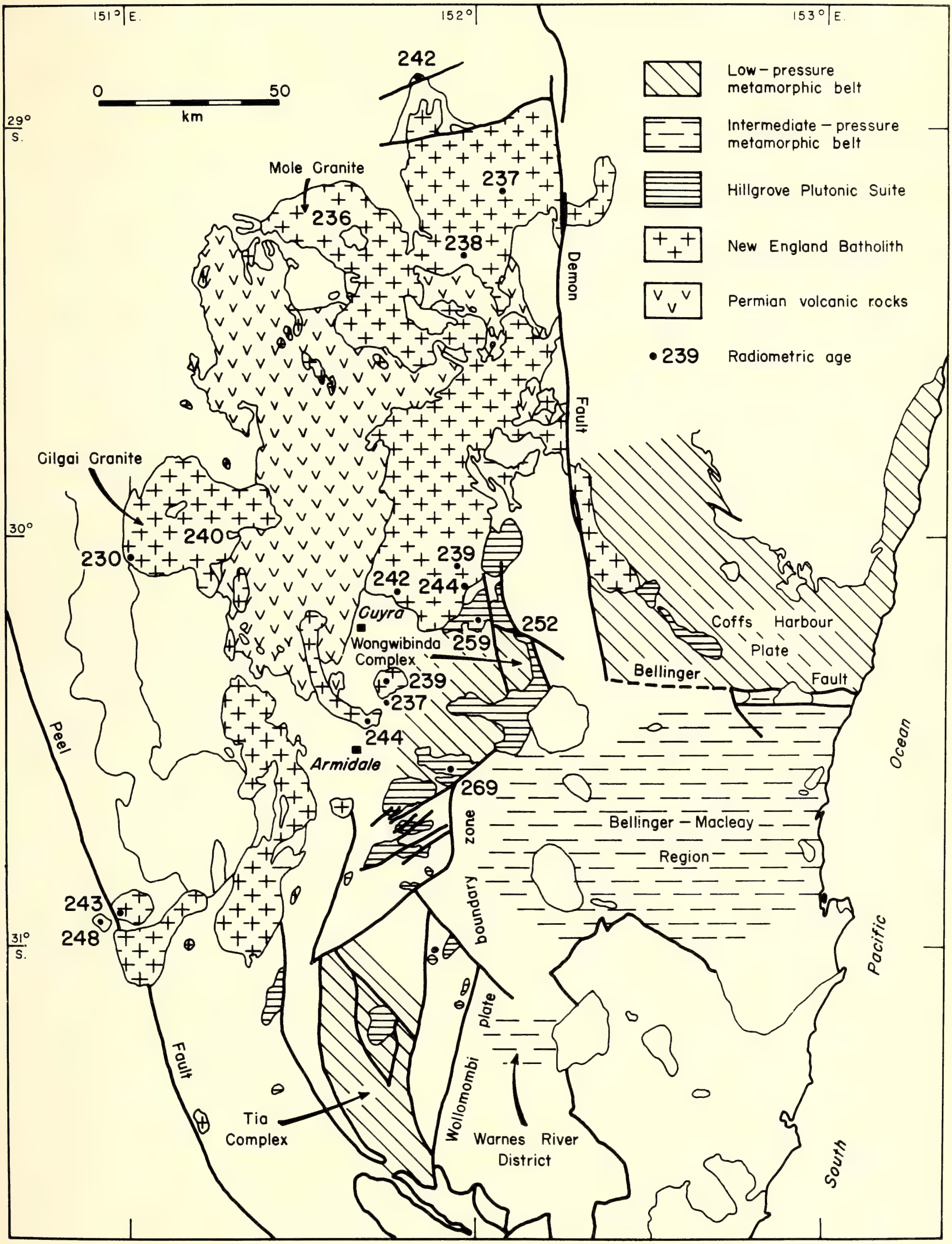
Fig. 4. Location of paired metamorphic belts and associated igneous rocks in New England. This map is modified from the 1:1 000 000 Geological Map of New South Wales, and some geological components, particularly the Tertiary basalts, have been omitted. The radiometric ages shown are in millions of years.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Low – pressure metamorphic belt
Intermediate – pressure metamorphic belt
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New England Batholith
Permian volcanic rocks
•239 Radiometric age
Mole Granite
Gilgai Granite
Demon Fault
Peel Fault
Cuyra
Wongwibinda Complex
Armidale
Coffs Harbour Plate
Bellinger Fault
Bellinger – Macleay Region
Wollomombi plate boundary zone
Tia Complex
Warnes River District
South Pacific Ocean
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# The Use of Inflection Surfaces in Descriptions of Folds

Russell J. Korsch

ABSTRACT. The form of inflection surfaces for both fold trains and fold stacks are developed for theoretical fold profiles. The fold train inflection surfaces for symmetrical folds are always normal to the axial surfaces but the fold stack inflection surfaces can be normal, oblique or parallel to the axial surfaces. For asymmetrical folds the above conditions need not apply. Inflection surfaces for field examples of mesoscopic folds are compared with the theoretical models.

## INTRODUCTION

In the description of folds attention has been paid mainly to folded surfaces or single folded layers and the relationships of folded surfaces or layers in fold trains and fold stacks are often neglected. The most useful way of describing fold shape up to the present has been by thickness parameters, $T$ and $t$ (Ramsay, 1962) and dip isogons (Elliott, 1965). Ramsay (1967) presents a comprehensive coverage of these two topics and his work has been extended by Hudleston (1973 a, b) particularly for single layer folds.

A useful parameter for describing one aspect of the geometry of folds is the locus of the lines of inflection of the limbs in a fold stack. This has been termed the inflection surface by Verhoogen *et al.* (1970, p. 153), who also took the inflection line as the limit of a single fold in the surface. This note expands the concept of inflection surfaces and examines the form of inflection surfaces both in theoretical fold profiles and actual field examples.

## THEORY

Most folded surfaces have a variable curvature in the profile plane. $dy/dx$ is a measure of the gradient of the curve and $d^2y/dx^2$ is the rate of change of the gradient of the curve. The crest (Point B in Fig. 1) has $dy/dx = 0$ and is a maximum turning point whereas the trough (Point A) is a minimum turning point. A point of inflection (Point C) is defined as the point where $d^2y/dx^2 = 0$ and $dy/dx$ does not change sign on either side of the point. For some folds the limbs are straight and hence the gradient does not change over this distance. Consequently $d^2y/dx^2 = 0$ for the entire length of the limb. Ramsay (1967, p. 347) defines the inflection point on such a limb as the midpoint of the straight portion, but that device is not rigorous because a single point of inflection does not exist. In this note two "change points" for each straight limb are used and are defined as points where $d^2y/dx^2 = 0$, and on one side of the point towards the hinge $d^2y/dx^2$ is changing, and on the other side away from the hinge $d^2y/dx^2 = 0$.

For folds with straight limbs between the hinge zones, a zone of zero curvature and constant

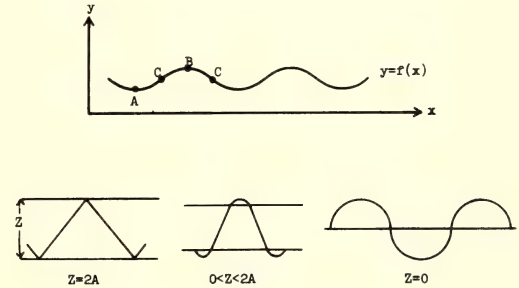


Fig. 1. Trough (A), crest (B) and points of inflection *(C)* for the trace of a single folded surface in the profile plane, and schematic illustration of the three general cases for $0 \leqslant Z \leqslant 2A$ for the zone of zero curvature *(Z)*.

gradient exists and is here defined as $Z$. $Z$ is related to the amplitude *(A)*, such that $0 \leqslant Z \leqslant 2A$. As the thickness of $Z$ decreases the chord length *(c)* increases according to the following formula for symmetrical folds: $Z = [1/\tan(\theta/2)]\cdot(\lambda/2-c)$, where

$\theta$ = interlimb angle,
$\lambda$ = wavelength,
$c$ = chord length, that is, the length of chord subtending the arc in the fold.

Substituting $0 \leqslant Z \leqslant 2A$ into this equation three general cases, as illustrated in Fig. 1, occur:

(1) $Z = 2A$. This is the case for angular folds because $c = 0$.

(2) $0 < Z < 2A$. This is the general case for folds with rounded hinges and straight limbs.

(3) $Z = 0$. The change points are coincident with the inflection point and the surface is a pure circular-arc parallel folded surface. Here $\theta = 0°$ and $\lambda = 2c$.

In the profile plane for most folded surfaces there exists either change or inflection points. These points represent lines of inflection or change lines from adjacent surfaces in a stack, and the locus of the lines in a stack is a fold stack

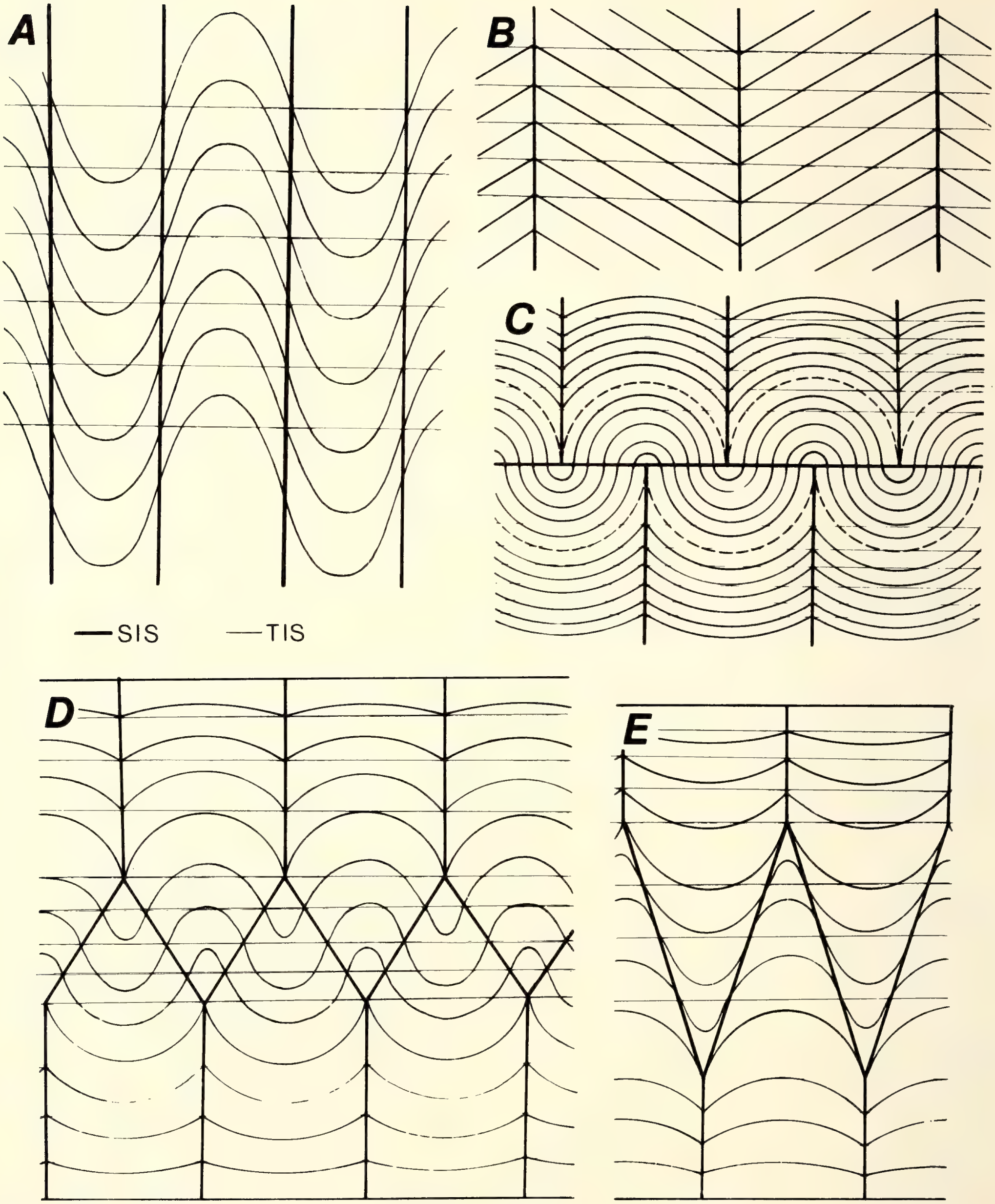


Fig. 2. Fold stack inflection surfaces and fold train inflection surfaces for theoretical fold models. A - idealised similar fold, B - angular fold, C - idealised pure circular arc parallel fold, D - idealised paraboloidal parallel fold, E - theoretical model of class 3 fold of Ramsay (1967).

inflection surface *(SIS)* or fold stack change surface. If inflection or change lines in a fold train are connected they produce a fold train inflection surface *(TIS)* or a fold train change surface. One problem which is encountered is that for some theoretical fold surfaces such as the outer zone of idealised pure circular arc parallel folds a point of inflection or two change points do not exist. In these cases the fold stack inflection surfaces and the fold train inflection surfaces have been drawn through the cusp point where $dy/dx$ approaches $\infty$.

Using a set of theoretical fold profiles the inflection surfaces for trains and stacks are illustrated in Fig. 2. Only symmetrical folds are being considered here. A useful measure is the angle between *SIS* and axial surface trace *(AS)* in the profile plane ($\phi$ = *SIS* < *AS*). $\phi$ ranges between 0° and 90°.

(1) $\phi = 0°$. Here *SIS* is parallel to *AS* and the folds are similar folds. Two special cases occur within this category:

(a) Idealised symmetrical similar folds (Fig. 2a). The *TIS* for an idealised symmetrical similar fold constitute a series of parallel lines perpendicular to *AS*. The *TIS* will be equidimensionally spaced only if the layers all had the same initial thickness. *SIS* also constitute a series of equidimensional spaced parallel lines. However the *SIS* are parallel to the *AS* and are midway between them. The spacing between *SIS* and the spacing between *TIS* differs, depending on $\lambda$, $A$ and the thickness of individual layers.

(b) Symmetrical angular folds (Fig. 2b). Again we have $\phi = 0°$ and *SIS* normal to *TIS*. However the main difference from the idealised symmetrical similar folds is that *AS* and *SIS* are coincident. For a single folded surface in a symmetrical fold the two *TIS* are separated by a distance $Z$ and the two *TIS* are coincident with the enveloping surfaces which define the outer limits of a fold.

(2) $\phi = 90°$. *SIS* is normal to *AS* and these folds are idealised circular arc parallel folds (Fig. 2c). The surfaces in the central zone have not suffered the effects of shortening and thickening, and hence all *SIS* are coincident with each other, and perpendicular to *AS*. Also within this zone the *TIS* are coincident with the *SIS*. Consequently class 1B folds of Ramsay (1967) have all *SIS* coincident with all *TIS* and perpendicular to *AS*. However, on moving out of the central zone into layers with class 1A style, then *SIS* becomes parallel to *AS*, and coincident with it in places, and the *TIS* becomes equidimensionally spaced perpendicular to *AS*.

(3) $0° < \phi < 90°$. This condition occurs with some fold surfaces of class 1C and class 3 (Figs 2d and 2e). The centres of the folds have become non-linear. Here *TIS* remains normal to *AS* but *SIS* defines a zigzag locus from one centre to the next. In Fig. 2d $\phi = 30°$ and in Fig. 2e $\phi = 18°$.

Johnson and Ellen (1974, Fig. 11) illustrate lines of discontinuity in ideal "concentric" folds. Their line of discontinuity is the same element as the *SIS* for paraboloidal parallel folds illustrated here (Fig. 2d). This indicates Johnson and Ellen's ideal "concentric" fold is not a pure circular arc parallel fold but is a paraboloidal parallel fold.

In conclusion, the fold train inflection surfaces of theoretical symmetrical fold profiles are always normal to the axial surfaces but the fold stack inflection surfaces can be normal, oblique or parallel to the axial surfaces. For symmetrical folds, these conditions need not apply.

FIELD EXAMPLES

The inflection surface parameters developed above have been applied to specific field examples. Figs 3 and 4 show examples of *SIS* and *TIS* determined for mesoscopic folds from the Coffs Harbour Block (Korsch, 1975). In Fig. 3 all folds were produced by the first period of deformation and the angle between the axial surface and *TIS* is, in almost every case, 90° whereas values for $\phi$ range from 5° to 31° (Fold A), 31° to 56° (Fold B) and 4° to 56° (Fold C). Values of $Z$ are very consistent within individual folds.

In comparison the folds in Fig. 4 produced by a second period of deformation show *SIS* almost parallel to *AS* and are almost coincident with them. This is typical of angular folds. The *TIS*, because of the asymmetry of the folds are not perpendicular to the *AS*. The angles range from 65° to 85°. For these folds $Z$ approximates very closely to 2A. Hence, in this example too, inflection surfaces for fold trains and fold stacks can be used to achieve an insight into the shape of folds.

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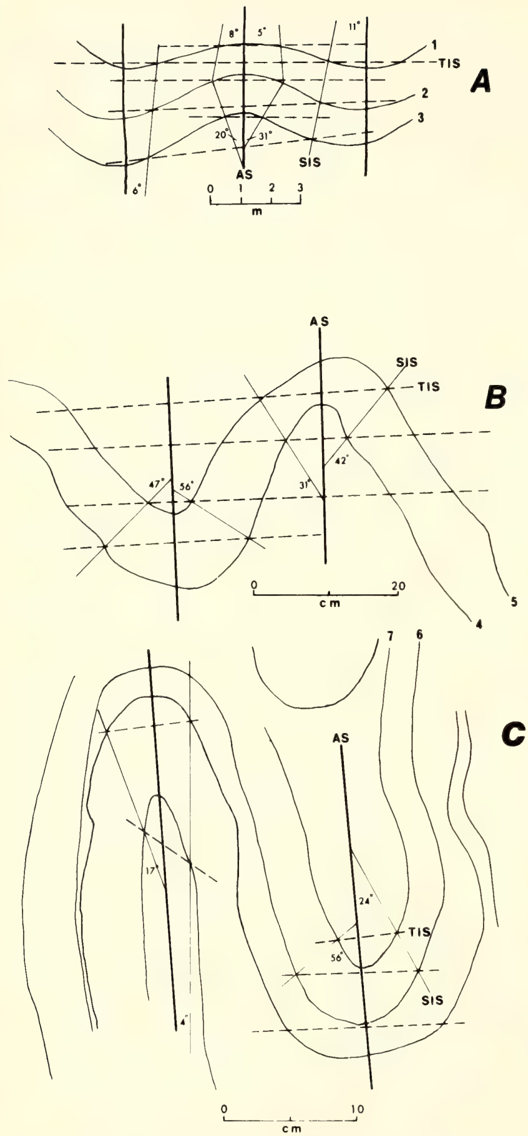


Fig. 3. Inflection surface patterns for some mesoscopic folds produced by the first period of deformation in the Coffs Harbour Block.

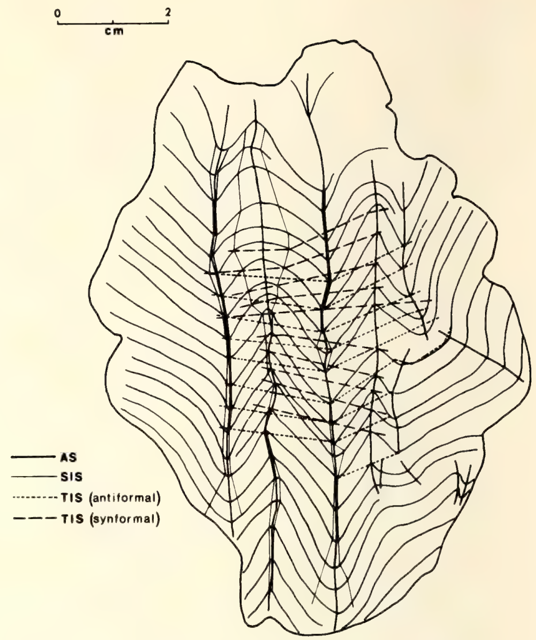


Fig. 4. Inflection surface patterns for mesoscopic folds produced by the second period of deformation in the Coffs Harbour Block.

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# The Demon Fault

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ABSTRACT. The Demon Fault is a major north-south trending ancient fault extending for over 200 km in length in the New England mobile belt in northeastern New South Wales. The most impressive feature is the consistent linearity. Previous authors have invoked strike-slip movements ranging from 30 km to 200 km, but it is possible conclusively to prove movements of the order of 17 km in a dextral sense. The Demon Fault is a fracture which has existed for a long period of time but along which there has been relatively little movement. It has possibly controlled sedimentation patterns and the emplacement of plutons.

## INTRODUCTION

The Demon Fault, named by Shaw (*in* Packham, 1969) is a near north-south trending ancient fault extending for over 200 km in the eastern part of the New England mobile belt in northeastern New South Wales (Fig. 1). The only faults of greater length in New England are the Peel Fault and the Hunter-Mooki Thrust which both occur in the western part of the belt. The Demon Fault which occurs in the Tablelands Complex of Korsch (1977) is a principal Palaeozoic and Early Triassic discontinuity cutting plutons of the New England Batholith (*sensu stricto*) and Stanthorpe Plutonic Suite as well as several stratigraphic units.

A dextral strike-slip movement of 30 km on this fault in the Tenterfield region has been proposed previously by Shaw (*in* Packham, 1969) but the present authors have proved movements of only 17 km. This amount of movement was based on the displacement of plutons, and hence the estimate is only a record of movement since the time of emplacement of the plutons. We consider that movement has possibly also taken place on this fault prior to the emplacement of the plutons. We have not been able to correlate stratigraphic or igneous units across the southern part of the fault. In the northern part correlations across the fault have been possible for some plutonic bodies.

Because of the paucity of correlations of units across the fault no direct evidence for the amount of movement is available. This lack of correlation has led authors such as Scheibner and Glen (1972), Runnegar (1974) and Leitch (1975) to infer a dextral strike-slip movement of the order of 100 km to 200 km.

The southern end of the Demon Fault is hidden beneath the Tertiary basalt pile near Ebor and its reappearance south of this pile has not been recognised. Leitch (1975) postulates that a northwest trending fault in the Nambucca Slate Belt is a southern extension of the Demon Fault. However others such as Scheibner and Glen (1972) and Runnegar (1974) imply that the Demon Fault ends at the western extension of the east-west trending Bellinger Fault. In the north the fault dies out in plutons of the Stanthorpe Plutonic Suite without any recognised extension of it into southern Queensland.

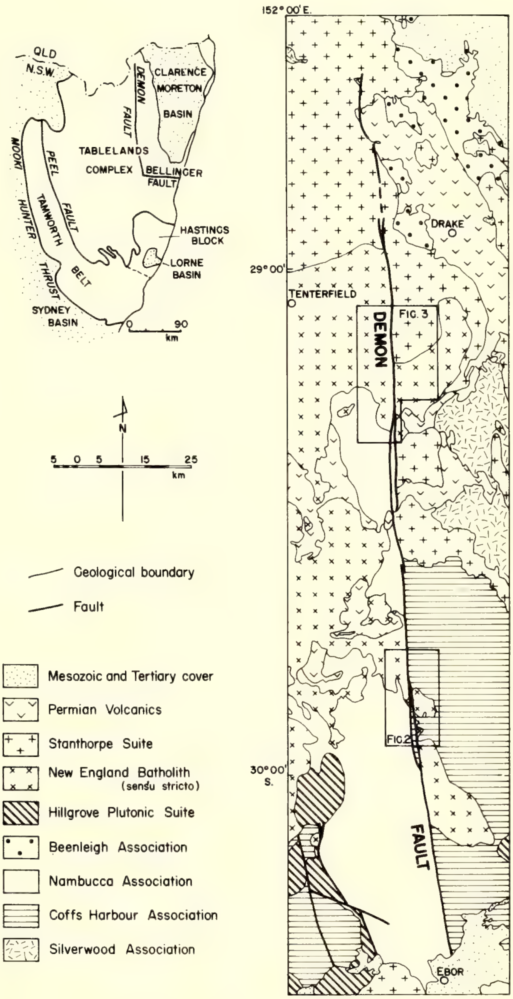


Fig. 1. Geological setting of the Demon Fault in the New England mobile belt. Nomenclature of the geological units follows Korsch (1977).

No previous detailed account of the fault exists. The results reported here are based on reconnaissance work over the length of the fault and detailed field mapping of two representative areas.

## GENERAL CHARACTERISTICS OF THE FAULT

The Demon Fault is an obvious linear feature on LANDSAT imagery and aerial photographs, and is clearly expressed in the topography. Fault line scarps occur at localities in both the northern and southern parts and deep V-shaped valleys along the faultline occur at other localities. The most impressive feature of the fault is its consistent linearity in that it has a relatively straight trace across the terrain for its entire length. As a fault it is predominantly a discrete fracture but at various places along its length it splits into two or more parallel or subparallel arms that dip nearly vertically.

Cataclastic effects of the Demon Fault are limited to a narrow zone a few metres to a few hundred metres wide. This fault zone is characterised by a lack of outcrop due to the preferential weathering and erosion of brecciated, deformed and weakened rocks.

The linear nature of the fault trace indicates a subvertically dipping plane. A thrust interpretation can be ruled out because characteristics which thrust planes exhibit on intersection with topography are absent.

## NEWTON BOYD AREA

In the Newton Boyd area (Fig. 2) the Demon Fault consists of a discrete fracture in the north which bifurcates in the south into discrete subparallel arms along which acid dykes have been intruded. To the west of the fault the Mt Mitchell Adamellite (Brunker *et al.*, 1969) has been emplaced into the Sara Beds (Korsch, 1978) which are a Permian sequence of coarsely-bedded chaotic conglomerate and thinly-bedded greywacke, siltstone and mudstone. Contact metamorphism of the Sara Beds up to the hornblende hornfels facies occurs in the aureole of the Mt Mitchell Adamellite. A K-Ar age of 245±5 m.y. for biotite from the Mt Mitchell Adamellite was reported by Rowley (1975).

To the east of the fault the Brooklana Beds (Leitch *et al.*, 1971), which consist of thinly-bedded mudstone, siltstone and rare greywacke, have been intruded by the Newton Boyd Granodiorite (new name, see Appendix) and the Chaelundi Complex (Binns and others, 1967). The Newton Boyd Granodiorite was mapped previously as a portion of the Mt Mitchell Adamellite occurring to the east of the Demon Fault. However, partial chemical analyses for several samples suggest that they are separate unrelated intrusions (Archer, 1975).

The Chaelundi Complex is a large composite body which is largely unmapped because of its inaccessability. At least three phases of intrusion are evident in outcrops along the Guy Fawkes River south of the Newton Boyd area.

Between the two parallel fault planes of the Demon Fault a sliver of highly ruptured sediments

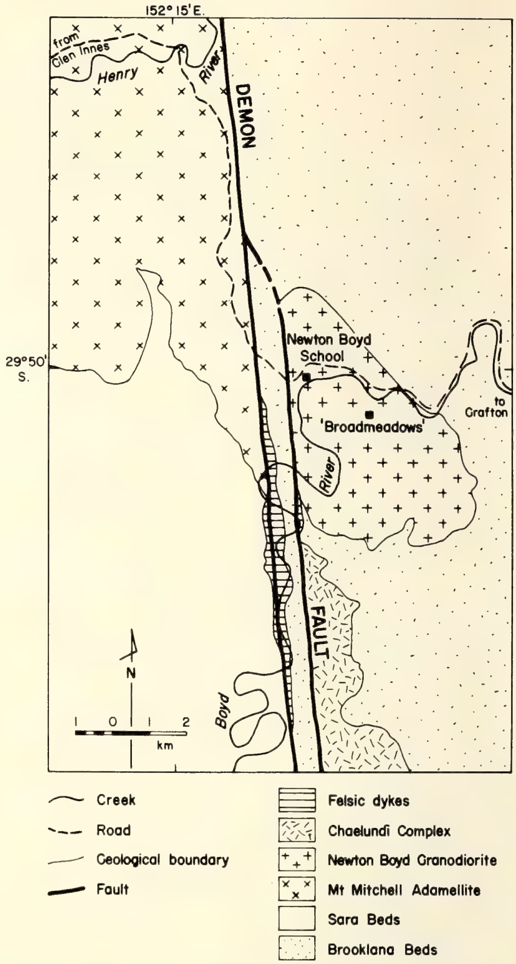


Fig. 2. Geological map of the Newton Boyd area showing the distribution of units on either side of the Demon Fault.

occurs in association with the acid dykes. It is considered that these sediments have affinities with the Brooklana Beds.

As can be seen from Figure 2 it is not possible to match stratigraphic or igneous units across the Demon Fault in the Newton Boyd area. This suggests that either the amount of horizontal displacement of units has been considerable or that the fault has existed for a long period of time and has exhibited some control over sedimentation patterns. If the fault existed prior to the intrusion of the plutons it might have aided their emplacement and then produced a truncated appearance by subsequent movement on the fault plane.

## DEMON CREEK AREA

In the Demon Creek area (Fig. 3) the Demon Fault consists of a single fracture for most of its

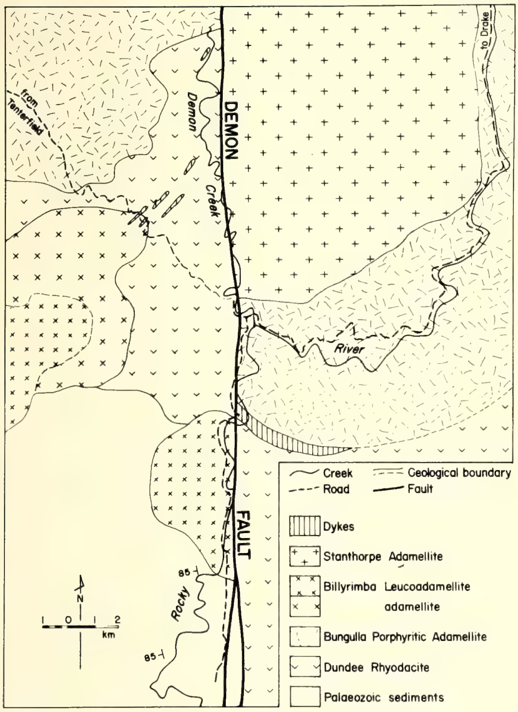


Fig. 3. The geology of the Demon Creek area showing the 17 km displacement of the boundary between the Dundee Rhyodacite and the Bungulla Porphyritic Adamellite.

length which in the south bifurcates into two sub-parallel fault planes. The eastern margin of the fault zone has suffered intense fracturing sub-parallel to the strike of the fault which is 357°. This zone consists of narrowly spaced chevron-type shears which are slightly oblique to the orientation of the fault. Slickenside orientations within these shears plunge 5° to 005°. Several individual plutons have been mapped in this area, most of them being truncated by the Demon Fault.

In the southern part of this area a large mass of sedimentary rocks occur to the west of the Demon Fault. These are indurated mudstone and sandstone and have been examined only in reconnaissance fashion. No fossils were found. A penetrative cleavage persists in the mudstone sub-parallel to bedding, suggesting the presence of isoclinal folding but because of poor outcrop and inaccessability no large scale folding has been detected. Korsch (1977) tentatively placed these rocks in his Nambucca Association.

The several discrete masses of the Dundee Rhyodacite (Flood *et al.*, 1977) have been regarded previously as parts of an intrusive adamellite-porphyrite (e.g. Wilkinson *et al.*, 1964) but the presence of distorted glass shards which are now devitrified suggest that the bodies had an ignimbritic origin. The Dundee Rhyodacite has been dated using K-Ar techniques as 242 m.y. by Evernden and Richards (1962). The two masses of the Dundee Rhyodacite which occur in the Demon Creek area have been intruded by the Bungulla Porphyritic Adamellite, and also by the Billyrimba Leucoadamellite and its associated adamellite (McConachy, 1975). However, the Bungulla pluton is not spatially adjacent to the Billyrimba masses and hence no inference can be made as to their order of intrusion. Finally, in the Demon Creek area the Stanthorpe Adamellite intrudes the Bungulla Porphyritic Adamellite. Rb-Sr ages of 237 m.y. and 222 m.y. for the Bungulla Porphyritic Adamellite and Stanthorpe Adamellite respectively were determined by Shaw (1964).

## DYNAMIC METAMORPHISM

Dynamic metamorphic effects, associated with movement on the Demon Fault have been recognised only in a narrow belt adjacent to the fault plane. The terms used here mainly follow Spry (1969).

Consistent effects were observed in the granitic plutons along the entire length of the fault. The first noticeable effects are the development of strained extinction in quartz, growth of secondary calcite and fracturing of plagioclase with minor granulation at some feldspar boundaries. The next stage produces severe fracturing and a crush breccia. There is some veining, biotites have been chloritised and severely kinked, feldspars have been fractured and quartz shows strain extinction. This stage grades into a protocataclasite where there has been chloritisation, kinking and shredding of biotite and fracturing and granulation of feldspar. A rock flour is beginning to develop. Adjacent to the fault cataclasites occur. There has been severe brecciation, fragmentation and granulation of quartz and feldspar to produce a very fine-grained green matrix. Minor relict quartz and feldspar are enclosed in the amorphous rock flour.

The first noticeable effect of the Demon Fault in the sedimentary rocks is kinking of cleavage in the fine-grained sediments. Adjacent to the fault there is severe granulation of the sediments to produce a cataclasite-like rock which still retains some original texture. Fracturing of the sediments is common, with the voids being infilled with quartz.

The acid porphyritic dykes associated with the fault in the Newton Boyd area were emplaced both before and after the movement had ceased. Some dykes show deformational effects such as strain extinction in quartz and minor fracturing of feldspars while others show no evidence of cataclasis.

## EVIDENCE OF MOVEMENT

The determination of the amount of slip on the Demon Fault depends on establishing a mismatch in the rocks on either side of the fault and then correlating accurately those stratigraphic and igneous units which were once continuous entities.

Shaw (*in* Packham, 1969) proposed a dextral strike-slip movement of 30 km based on the displacement of the Stanthorpe Adamellite east of Tenterfield. However in the same area the authors

can prove a maximum determinable horizontal displacement of only 17 km with the east block moving south relative to the west block. The authors base this movement on the displacement of the contact between the Dundee Rhyodacite and Bungulla Porphyritic Adamellite. However this only indicates that there has been a strike separation of 17 km since the emplacement of the Bungulla Porphyritic Adamellite about 237 m.y. ago. Because the Stanthorpe Adamellite has also been displaced the movement was later than 222 m.y. ago. It does not give any indication of the possibility of movement on the fault prior to the emplacement of the plutons and nor does it give any indication of a vertical component to the movement.

Slickensides in the fault zone plunge shallowly to the north. In the Demon Creek area they plunge 5° to 005° while those in the Newton Boyd area plunge 18° to 342°. This suggests that there has been a slight vertical component to the movement.

The plutonic rocks in the vicinity of the Demon Fault are heavily fractured and in the Demon Fault area these fractures differ in orientation across the fault. The dominant orientation in the western block is 065° although subsidiary orientations of 010°, 040° and 145° were also observed. In some cases sinistral strike-slip displacements of up to 15 m occur along some of the 065° fractures. To the east of the fault the predominant strike for fractures is 035° although a subsidiary orientation of 140° occurs also. This suggests that there has been some anti-clockwise rotation of the fractures east of the fault relative to those west of the fault (McConachy, 1975).

In the Newton Boyd area Archer (1975) measured subvertical joints from plutons on both sides of the fault and also lineaments on aerial photographs. In the Mt Mitchell Adamellite the predominant orientation for joints was 135° with subsidiary orientations of 160° and 040°. For lineaments the predominant orientation was 060° with subsidiary orientations at 035° and 005°. To the east of the fault in the Newton Boyd Granodiorite the predominant joint orientation was 070° with subsidiaries at 015° and 160° and the main lineament orientation was 135° with a secondary orientation of 005° which is subparallel to the fault plane.

The confusing picture presented by the joint and lineament patterns from both sides of the Demon Fault does not allow the establishment of a concise movement pattern. More detailed work over the whole length of the fault will need to be carried out before a comprehensive understanding of the relationship of the fractures to the fault is reached.

Since the Early Triassic the Demon Fault appears to have been extinct, although it is possible that associated with the uplifting of New England in Tertiary times there was approximately 120 m of dextral strike separation as is suggested by offsets in tributaries of the Demon Creek which flow from east to west across the fault zone.

Several authors have postulated a much greater strike-slip movement on the Demon Fault than the here presented evidence shows. Scheibner and Glen (1972) invoked a large unspecified amount of dextral movement on the Demon Fault to account for the intense deformation and regional metamorphism in the Nambucca Slate Belt. Runnegar (1974) correlated rocks in the Texas region in southern Queensland with those in the Coffs Harbour Block and assumed that all structures to the east of the Demon Fault have been displaced 100 km to 150 km dextrally during the Permian or Triassic. The correlation of rocks in the Texas area with those of the Coffs Harbour Block has not been proved and is not supported by Korsch (1977).

Leitch (1975) also invokes a dextral displacement of at least 200 km for the Coffs Harbour Block but correlatives of these rocks to the west of the Demon Fault in the border rivers region or southern Queensland has not been established conclusively.

Hence although movements on a large scale on the Demon Fault might have occurred prior to the emplacement of plutons of the New England Batholith *sensu stricto* and Stanthorpe Plutonic Suite no definitive correlations have been made to indicate the amount of displacement.

## TECTONIC IMPLICATIONS

As outlined above, most previous tectonic models for New England invoke a large dextral strike-slip movement of the order of 100 km to 200 km for the Demon Fault. The authors proved a horizontal displacement of at least 17 km. The matching of geological features across the fault over distances postulated by previous authors has not been possible. Such a movement, if it occurred, will only be proved after much more detailed work, involving the structural mapping of all rocks, chemical analyses, and radiometric dating of the plutons, has been undertaken.

Until such a displacement is conclusively proved the authors prefer an alternative interpretation which does not invoke strike-slip movements of such a large amount. The authors suggest that there have been no large scale movements. Instead, the fault was a linear feature which persisted for a long period of time, with the rocks adjacent to it being subjected to minor horizontal and vertical displacements from time to time. The fault possibly controlled sedimentation, particularly of Permian rocks such as the diamictite, conglomerate and finer-grained sediments of the Nambucca Association.

The Wongwibinda Fault (Fig. 1) defines the western boundary of the Nambucca Association in the southern part of the area. The Abroi Granodiorite, migmatites and Rampsbeck Schists of Binns (1966) occur to the west of the Wongwibinda Fault and are now more deeply exposed than the Nambucca Association sediments, suggesting that on the Wongwibinda Fault the major vertical component of movement was western block upwards.

A complementary movement on the Demon Fault of eastern block upwards might have led to the development of a trough in which the sediments of the Nambucca Association were deposited. On the other hand the Demon and Wongwibinda faults may have been coincident reaching their present positions by rifting apart thus producing a trough

in between them. Mylonite produced by movement on the Wongwibinda Fault is considerably different to the dynamic metamorphic products of the Demon Fault and hence does not support this possibility.

The fault probably controlled the emplacement of many of the plutons because several plutons abut against the fault but do not appear to have a conjugate displaced portion on the opposite side. The fault might have bounded their emplacement and subsequent minor movements produced the dynamic metamorphic effects which are now observed.

The nature of strike-slip faults is the subject of debate currently occurring in the literature. Wilson (1965) introduced the term transform fault for a fault which he regarded as fundamentally different from a transcurrent fault. This approach has been followed by others such as Hill (1974) and Freund (1974). However, some authors such as Wellman (1971) and Garfunkel (1972) regard the terms transform and transcurrent as being synonymous suggesting only one kind of strike-slip fault.

Freund (1974) lists sixteen properties to distinguish transform from transcurrent faults. Several of the properties are difficult to apply to ancient faults because they have been derived from active faults and hypothetical models.

The Demon Fault exhibits properties which fit descriptions for both transform and transcurrent faults. The single, straight nature suggests a transform but the small amount of displacement and absence of adjacent parallel faults suggest a transcurrent nature. Transforms terminate at structural features such as ridges or trenches and there are only six types which can occur (Wilson, 1965). A problem arises in trying to recognise either a ridge or trench system at the extremities of the Demon Fault, and there appears to be no geological structures in these areas which could possibly be interpreted as either a ridge or a trench. Hence the exact character of the Demon Fault is uncertain. It is not possible to determine whether the Demon Fault is a transform or transcurrent fault.

In conclusion, the authors find no evidence to suggest that there has been large-scale movements of a strike-slip nature on the Demon Fault. Consequently, tectonic models may have to be revised to account for a Demon Fault along which there are only small strike-slip displacements.

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## APPENDIX

### DEFINITION OF THE NEWTON BOYD GRANODIORITE

Derivation of Name: Newton Boyd School (GR 537304, Grafton, 1:250 000).

Synonymy: Previously considered to be part of the Mt Mitchell Adamellite occurring to the east of the Demon Fault. Partial chemical analyses suggest that these are two separate plutons.

Lithology: Medium-grained biotite granodiorite, mainly of equigranular texture but becoming slightly porphyritic near its margins.

Definition of Boundaries: The pluton intrudes the Brooklana Beds producing a narrow albite-epidote hornfels zone. The western margin of the pluton has been truncated by the Demon Fault.

Type Area: In the Boyd River to the east of Broadmeadows homestead at GR 539303 (Grafton 1:250 000).

Age: Unknown, but it intrudes the Brooklana Beds which are postulated to be Late Palaeozoic.

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# The Permian and Mesozoic of the Merriwa-Binnaway-Ballimore Area, New South Wales

F. C. LOUGHNAN AND P. R. EVANS

ABSTRACT. In the Merriwa-Binnaway-Ballimore area a succession of essentially horizontal, fluvial strata, ranging in age from Late Permian to Middle Jurassic, forms a thin veneer draped over the structural high of Carboniferous granite and Middle Palaeozoic geosynclinal rocks that separates the northwestern Sydney Basin from the Coonamble Embayment of the Surat Basin. Subdivision of these strata has been possible by use of two key units; the Wollar Sandstone of mainly Triassic age, and the Ukebung Formation, which over most of the area forms the base of the Jurassic succession. The Ukebung Formation is of particular interest in that it comprises predominantly kaolinite clayrock or flint clays that form the principal source of refractory kaolinite in Australia. Coal occurs in the Upper Permian Dunedoo Formation and is also associated with the kaolinite clayrocks of the Ukebung Formation but at present it appears of little commercial value. From examination of microfloral assemblages, the Ukebung Formation is of Toarcian (Late Early Jurassic) age whereas the youngest Triassic strata in the area, those of the Wallingarah Formation, were laid down in the Early Anisian (Early Middle Triassic). A hiatus in sedimentation of about 30 m.y., therefore, preceded deposition of the Ukebung Formation.

## INTRODUCTION

The Merriwa-Binnaway-Ballimore area, which is located 200 km to 300 km northwest of Sydney, extends across the broad structural high of folded, Middle Palaeozoic, geosynclinal strata and Carboniferous granite that separates the northwestern Sydney Basin from the Coonamble Embayment of the Surat Basin. Overlying these eroded basement rocks with a marked angular unconformity is a relatively thin succession of Late Permian and Mesozoic fluvial sediments that for the most part are essentially horizontal although in close proximity to some of the basement inliers dips of the order of 30 degrees have been noted.

Until rather recently these sediments attracted little attention and, apart from early reconnaissance surveys by Kenny (1928), Kenny & Lloyd (1935) and Lloyd (1935), and subsequent papers by Dulhunty (1939a, 1939b), little had been published on the geology of this extensive tract of country. However, between 1971 and 1975 students at the University of New South Wales, namely Higgins (1971), Arditto (1972), Bell (1973), Corkery (1973), Kemp (1973), Dixon (1974), Cosis (1975), Dale (1975) and Wallin (1975), undertook detailed geological mapping in the area extending from Binnaway in the north (Fig. 1) to the vicinity of Sandy Creek south of Cobborah. Their work together with the results furnished from subsurface explorations by Newbold General Refractories Ltd., near Merrygoen (Callender, 1974) and by Australian Consolidated Industries Ltd. (Pollington, 1973) between Cobborah and Elong Elong, has established the presence of at least two relatively persistent key units. The first of these, termed the *Boulderwood Conglomerate* by Higgins (1971), represents the westward extension of the Lower Triassic *Wollar Sandstone* (Hind & Helby, 1969), which crops out prominently in the Goulburn Valley to the south of Merriwa, whereas the younger *Ukebung Formation* (Higgins, 1971) comprises mainly flint clays or kaolinite clayrocks, that are being exploited at several localities for use in the manufacture of refractories. With the aid of these key units Higgins & Loughnan (1973) subdivided the stratigraphic succession in the area between Merrygoen and Digilah (Table 1). Essentially the same sequence was recognised by Dulhunty (1973), who unfortunately, in naming some of the units, gave new meanings to several of the older terms of Kenny (1928) and Lloyd (1935).

The work of these authors has been extended with field and laboratory studies and from the results it is apparent that some modifications to the stratigraphic nomenclature are necessary. The revised scheme, devised after consultation with representatives of the N.S.W. Geological Survey, is also given in Table 1.

## PERMIAN

### Liamena Volcanics

Throughout most of the area the Middle Palaeozoic basement rocks are immediately overlain by fluvial strata of the Upper Permian Dunedoo Formation. Nevertheless, in places, notably around some of the basement inliers, the Permian has been overlapped by Mesozoic sediments and, moreover, near Liamena and extending southwest across the Talbragar River to the Dunedoo-Cobborah road, a distance of about 6 km, is a succession of horizontal volcanic rocks that appear, at least in part, to underlie the Dunedoo Formation. Kenny (1928) termed these the *Liamena Rhyolite* and concluded that they comprise about 10 m of extensively altered, porphyritic, acid lavas, which, during emplacement, incorporated angular blocks of the basement. Bell (1973) however, found volcanic sandstone interbeds within the lavas whereas Kemp (1973) noted that the groundmass of the volcanic rocks is composed mostly of welded shards and concluded that ignimbrites constitute part of the

succession. In view of these findings the unit has been renamed the *Liamena Volcanics*.

The volcanics are poorly exposed and their relationship with the Dunedoo Formation has not been resolved. Possibly they correlate with either the Late Carboniferous Rylstone Rhyolite, which crops out extensively in the area to the east and south east of Mudgee, or the Early Permian Boggabri Volcanics of the Gunnedah Basin to the northeast of Binnaway. However, Kenny (1928) reported that a bore near Liamena penetrated the complete thickness of the volcanics and encountered what appeared to be Permian conglomerate ("boulder beds") below. Hence, the formation has been tentatively grouped with the Dunedoo Formation.

Dunedoo Formation

The Dunedoo Formation (Higgins & Loughnan, 1973) crops out mainly on the floors and sides of pre-Late Permian valleys cut into the basement rocks. Nevertheless, in the northern part of the area it is also exposed around the margins of a number of inliers that mark the extension of the basement high (Higgins, 1971; Arditto, 1972: Dixon, 1974). The thickness of the formation is generally between 30 m and 50 m but considerable variation occurs depending upon the basement topography. Thus, it has been overlapped by Triassic strata at several of the inliers (Higgins, 1971; Arditto, 1972) and by the Pilliga Sandstone northeast of Leadville whereas in the vicinity of Ballimore it is probably in excess of 100 m.

The formation comprises a variety of fluvial sediments some of which contain abundant *Glossopteris* impressions. In the type section described by Higgins & Loughnan (1973) the basement rocks are immediately overlain by a breccia composed of fragments of the basement and this, in turn, is succeeded by petromictic and quartz-pebble conglomerate above which is a variable sequence of sandstone, cherty siltstone or porcellanite, dense kaolinite clayrock, carbonaceous shale and lenticular seams of coal and torbanite. Kenny (1928) believed that the basal breccia represents tillite but close examination of these rocks by Higgins (1971), Bell (1973), Corkery (1973) and Kemp (1973) failed to verify the presence of striated boulders or to reveal other evidence indicative of ice transport. Moreover, as Higgins & Loughnan (1973) and Bell et.al. (1974) stressed, the association of these rocks with sediments composed almost exclusively of kaolinite, a mineral that is generally considered characteristic of warm, humid regions (Millot, 1964), is difficult to reconcile with glacial conditions. Furthermore, where the Permian has been overlapped by the Triassic, a similar breccia frequently forms the basal beds of the latter system. It would appear more likely that the breccia in the basal Permian is of colluvial origin and that its development was essentially a function of the basement topography. Nevertheless, as Wallin (1975) and Dale (1975) suggested, it is possible that the breccia represents reworked Carboniferous fluvioglacial deposits.

The sandstones vary from fine- to coarse-grained and contain in places channel structures, trough crossbedding and lag conglomerates. They range from quartzose to quartz-lithic and quartz-feldspathic but the matrices with few exceptions are predominantly kaolinitic.

Of the finer grained rocks the porcellanites

TABLE 1

SUBDIVISIONS OF THE PERMIAN, TRIASSIC AND JURASSIC

| | | KENNY (1929) | LLOYD (1935) | HIGGINS AND LOUGHNAN (1973) | DULHUNTY (1973) | THIS PAPER |
|---|---|---|---|---|---|---|
| JURASSIC | UPPER | MUMBEDAH BEDS | ERSKINE BEDS | PILLIGA SANDSTONE | PILLIGA SANDSTONE | PILLIGA SANDSTONE |
| | MIDDLE | UPPER MERRYGOEN BEDS | BALLIMORE COAL MEASURES | DIGILAH FORMATION | PURLAWAUGH FM.: COMIALA SHALE MEMBER<br>MERRYGOEN IRONSTONE MB. | GARRAWILLA VOLCS.<br>DIGILAH FM. |
| | LOWER | | | UKEBUNG CREEK CLAYSTONE | PURLAWAUGH FM.: BUTHEROO SHALE MEMBER<br>BALLIMORE FM.<br>GARRAWILLA VOLCS | UKEBUNG FM. |
| TRIASSIC | UPPER | | | | TALBRAGAR FM.: BOOTHENBA SS. MB.<br>SAXA SHALE MB.<br>RIVERS SS. MB. | |
| | MIDDLE | LOWER MERRYGOEN BEDS | LOWER BALLIMORE BEDS | WALLINGARAH CREEK FM. | WOLLAR SANDSTONE | WALLINGARAH FM. |
| | LOWER | | | BOULDERWOO CONGLOMERATE | | WOLLAR SANDSTONE |
| PERMIAN | UPPER | DUNEDOO COAL MEASURES | | DUNEDOO FORMATION | ULAN COAL MEASURES | DUNEDOO FORMATION |

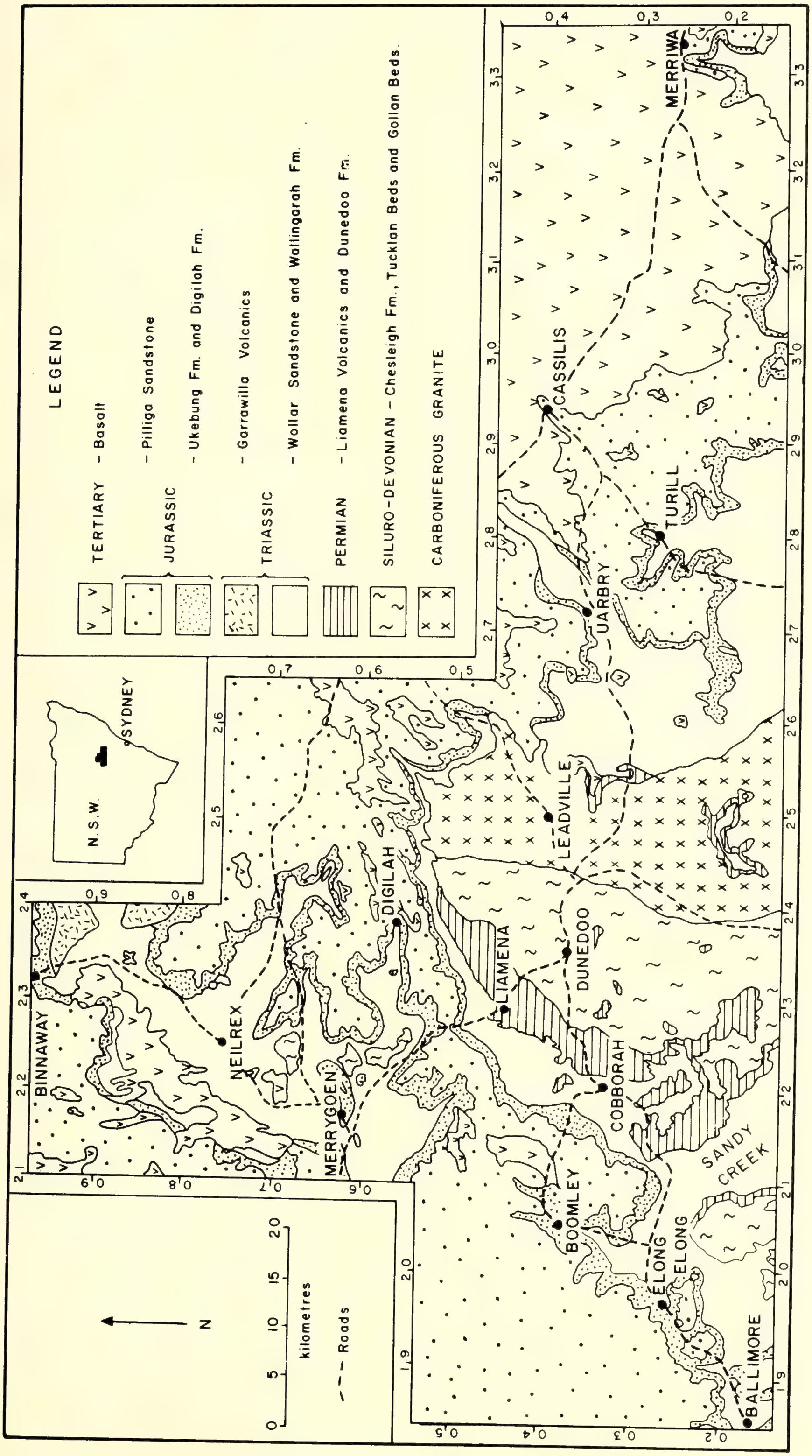


Fig. 1. Geological sketch map of the Merriwa-Binnaway-Ballimore area.

are the most conspicuous. They are similar to those forming part of the Illawarra Coal Measures along the western margin of the Sydney Basin in that they consist of chalcedonic, kaolinitic siltstone and frequently contain plant remains. Indeed, at several localities, notably "Oakfield" (G.R. 224033) to the east of Cobborah, quarries have been developed to exploit these fossil leaf impressions. Tree stumps are also common in the porcellanites and in a creek bed on "Goodiman", located between Spring Ridge and the Gulgong-Dunedoo Road to the southeast of the area shown in Fig. 1, Wallin (1975) counted more than 30 sites of tree growth in an area less than 100 $m^2$.

The kaolinite clayrocks occur in beds up to a metre thick, although few exceed 25 cm, and like the porcellanites with which they are commonly associated, represent overbank accumulations. They are mostly light-coloured, very fine-grained and particularly dense although Cosis (1975) described several such beds located within a few metres of the overlying Wollar Sandstone in the Sandy Creek area (G.R. 223015) where the bulk of the rock consists of vermicular kaolinite crystals, many of which are in the form of rouleaux. The matrix bonding these crystals comprises similarly oriented kaolinite microlites that yield aggregate birefringence and extinguish parallel to the bedding. Quartz is a common contaminant of the fine-grained kaolinite clayrocks and may constitute as much as 15%, whereas hematite is sufficiently abundant in places to impart a red-brown colour and these clayrocks are similar in appearance and composition to the "chocolate shales" of the Triassic Bald Hill Claystone in the southern part of the Sydney Basin.

The coal is of low to medium bituminous rank and generally has a high ash content. It occurs in thin lenticular seams, many of which have been explored either by shafts or adits but the only serious attempt at commercial exploitation was near Saxa Crossing (G.R. 195015) where a seam, varying in thickness up to 2.1 m, was worked about the turn of the century for the local market (Jones, 1919).

## PERMIAN-TRIASSIC

### Wollar Sandstone

Throughout much of the area the Wollar Sandstone forms bold outcrops and, coupled with a limited thickness, it has proven useful for field mapping. It comprises mainly massive and cross-bedded sandstone and pebbly conglomerate with some shaly interbeds but where it laps on to the basement inliers, breccia with clasts up to 25 cm in diameter (Corkery, 1973), is the dominant lithology. The conglomerates, which apparently represent braided stream accumulations, are mostly petromictic near the base but higher in the succession quartz pebbles become increasingly abundant.

The sandstones have a variety of sedimentary structures including ripples, channel-lags, scour-and-fills and fining-upward sequences and, as Wallin (1975) and Dale (1975) observed, originated at least in part, as point-bar accumulations. They are composed of subangular to subrounded quartz grains with subordinate amounts of rock fragments and decomposed feldspars set in a predominantly kaolinitic matrix although illite, generally degraded in part, is frequently present. Hematite and limonite are common cementing agents and in places fill joints and other fractures in the rock.

According to Hind and Helby (1969), the Wollar Sandstone in the upper Goulburn Valley has a thickness of about 360 m. But, considerable thinning takes place to the west and in the area between Turill and Ballimore the formation rarely exceeds 20 m and frequently is less than 5 m. It is believed to be conformable with the underlying Dunedoo Formation but because of abundant talus the contact is rarely observed. Furthermore, since it overlaps the Dunedoo Formation around some of the basement inliers, possibly a disconformity separates the two formations.

## TRIASSIC

### Wallingarah Formation

This unit, previously termed the Wallingarah Creek Formation by Higgins & Loughnan (1973) and the Talbragar Formation by Dulhunty (1973), conformably succeeds the Wollar Sandstone but, unlike the latter, outcrops are poor and frequently the only surface manifestation is a litter of ferruginous nodules and concretions. Nevertheless, close examination of sporadic exposures in creek beds and road cuts has revealed that the strata are of fluvial origin and comprise channel-fill sandstone and conglomerate in addition to over-bank deposits such as shale, siltstone, ironstone, infrequent thin beds of kaolinite clayrock and, in the Ballimore area, sparse coal seams. It is also apparent that the lithological succession undergoes considerable regional variation. Thus, in the Goulburn Valley to the southwest of Merriwa, the formation is 40 m thick and consists mainly of flaggy sandstones with inter-bedded siltstone, shale, "chocolate shale" and kaolinite clayrock. Dulhunty (1973) termed this facies the *Rivers Sandstone Member*. West of Turill however, the flaggy sandstones are either sparse or absent and silty shale containing numerous siderite concretions, predominates. This shaly facies is well-exposed on the northern bank of Butheroo Creek at "Langdon" (G.R. 239069) where the thickness is more than 25 m, and also in a roadside quarry 0.5 km north of Merrygoen (G.R. 217063). But, to the north and south of the Merrygoen-Butheroo Creek area further facies changes are apparent with massive sandstone and conglomerate becoming increasingly abundant (Higgins, 1971; Arditto, 1972; Corkery, 1973; Kemp, 1973; Dixon, 1974). In the Sandy Creek area Wallin (1975) recognised three unnamed subunits within the formation, the lowermost of which tends to be lenticular and consists mainly of ferruginous shales and argillaceous sandstones. This is succeeded by up to 12 m of sandstone that resembles the Wollar Sandstone in forming bold outcrops. Cross-bedding, ripples and scour marks are prevalent in this sandstone and both Wallin (1975) and Dale (1975) established from measurements made on these structures that sediment transport was from the east and south east. The uppermost subunit is composed of shale, siltstone and sandstone with sporadic thin beds of fine- to coarse-grained kaolinite clayrock and, a little above the base, a prominent ichnite horizon, which Cosis (1975), Dale (1975) and Wallin (1975) found useful as a marker. Both

Higgins (1971) and Bell (1973) recorded the presence of similar ichnite horizons at approximately the same stratigraphic level in the Merrygoen and Cobborah areas respectively.

Near the top of the formation in the vicinity of Ballimore is a light-coloured sandstone, which Dulhunty (1973) named the *Boothenba Sandstone Member*. It has a probable maximum thickness of 25 m and is composed of abundant angular rock fragments, many of which have been derived from the basement, with subordinate amounts of quartz set in a predominantly kaolinitic matrix.

Over much of the area the thickness of the Wallingarah Formation rarely exceeds 40 m. Nevertheless, Cosis (1975) reported that near Medway (G.R.217028) it is more than 120 m and, from examination of the logs of the two bores sunk at Ballimore Hill (G.R. 186021), Lloyd (1935) estimated a similar thickness for what he termed the "Lower Ballimore Beds". It would appear therefore, that the Wallingarah Formation thickens appreciably to the southwest of the area covered in Fig. 1 and, if this trend is maintained, a considerable development of Triassic strata must underlie the younger Mesozoic rocks in the south-east sector of the Coonamble Embayment.

Near Bong Bong Creek (G.R. 257057) toward Coolah, the Wallingarah Formation thins appreciably and eventually is overlapped by younger Strata.

TRIASSIC-JURASSIC

Garrawilla Volcanics

The Garrawilla Volcanics are mainly developed in in the Mullaley-Tambar Springs area between Gunnedah and Coonabarabran (Bean, 1974). Nevertheless, they extend to the southwest at least as far as the Castlereagh River near Binnaway where they overlie the Wallingarah Formation and in turn, are succeeded by the Ukebung Formation (Dixon, 1979).

According to Bean (1974), the volcanics have a maximum thickness of 180 m and comprise vesicular and nonvesicular alkali basalt, including hawaiite and mugearite, with soda trachyte and pyroclastic material. However, in the Borah Creek Bore,which penetrated a complete sequence of the formation about 70 km north of Binnaway, interflow sediments that are mostly red and vary in composition from quartzitic to kaolinitic and montmorillonitic, are particularly abundant. Moreover, many of the individual flows can be observed passing upward into fossil soil horizons.

Dixon (1974) has shown that the volcanics in the vicinity of Binnaway were laid down on an eroded s surface and, in at least one locality, they overlap the Wallingarah Formation and rest directly on the Wollar Sandstone.

On the western side of the Castlereagh River to the south of Binnaway, some of the basalts mapped as Tertiary in age (Fig. 1) are overlain by montmorillonitic clay and near "Sherbourne" homestead (G.R. 229090), by red kaolinitic claystone that does not differ appreciably in appearance and composition from some of the interflow sediments of the Garrawilla Volcanics evident in the Borah Creek Bore. Hence, it is possible that the Garrawilla Volcanics extend farther to the south and west than is shown in Fig. 1. Pertinent in this respect, Arditto (1972) recorded the presence of basaltic sills at the base of the Wallingarah Formation near the Bullinda inlier (G.R. 244064) and considered that they are probably referable to the Garrawilla Volcanics.

By use of the potassium-argon dating method, Dulhunty and McDougall (1966) and Dulhunty (1972) have established ages for the Garrawilla Volcanics ranging from 201.5 m.y. to 171.5 m.y. It would appear therefore, that the extrusions extended from Late Triassic to Middle Jurassic.

JURASSIC

Ukebung Formation

The Ukebung Formation, which represents a sequence of braided-stream, channel-fill and flood-plain deposits, is composed mainly of kaolinite clay-rocks with variable amounts of quartz-lithic sandstone, shale, ironstone and coal. The clay-rocks are of particular interest for not only do they form the principal source of refractory kaolinite in Australia but furthermore, their distinctive mineral composition renders easy recognition and hence, they are particularly useful for field mapping. Originally the formation was termed the *Ukebung Creek Claystone* by Higgins (1971) and Higgins & Loughnan (1973), and subsequently, the *Butheroo Shale Member* of the Purlawaugh Formation by Dulhunty (1973) but, since the bulk of the rocks is neither claystone nor shale, both terms were considered inappropriate.

The formation has been traced by intermittent outcrop from "Rothbury" (G.R. 313015) near Merriwa, westward to beyond Ballimore, a distance of nearly 120 km, and to the north as far as Binnaway. Nevertheless, the clayrocks are not particularly resistant to erosion and, as a result, exposures frequently are poor. Moreover, in places they can be observed grading laterally into quartzose and quartz-lithic sandstones that are virtually indistinguishable from many such rocks occurring within the Wallingarah Formation. Arditto(1972) believed that the formation is discontinuous on the southern side of Butheroo Creek and certainly to the north-west of Leadville and also in the Sandy Creek area it has been overlapped by younger strata.

The contact of the Ukebung and Wallingarah Formations is rarely observed in outcrop. Never-the less, Corkery (1973) found evidence in the "Berowra" area (G.R. 2455054) of a disconformity separating the two units and certainly this is consistent with the palynological data. But, in the exposure on the northern bank of Butheroo Creek at "Langdon" (G.R. 239069) and also in the cores of many of the bores in the Merrygoen area (Callender, 1974), the contact appears completely conformable.

The type section for the formation has been taken as the interval between 7.54 m and 18.33 m in the core of Newbolds General Refractories DH3 Bore (Fig. 2), which penetrated a complete

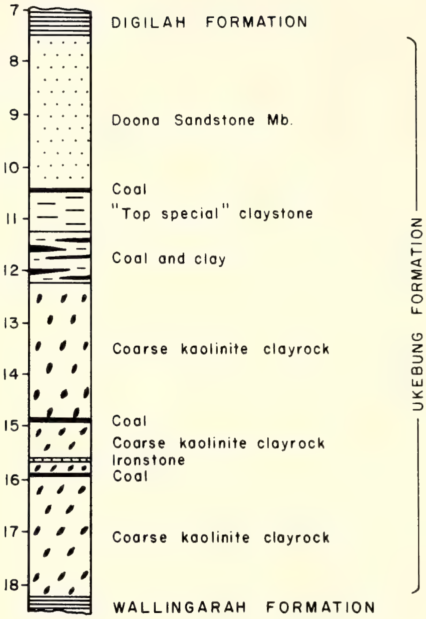


Fig. 2. Type section of the Ukebung Formation in Newbolds General Refractories' DH3 Bore (G.R. 218062).

sequence of the unit 0.56 km east of Merrygoen (G.R. 218062). In this area the formation comprises variable lenticular beds of arenaceous and rudaceous kaolinite clayrock with some shale and thin stringers of coal overlain by a conspicuous unit, 0.48 m thick, of unusually dense, fine-grained claystone known in the refractory industry as "special claystone". Above this is 0.2 m of coaly matter succeeded by nearly 3 m of kaolinitic, quartzose sandstone loosely referred to as the "Main Sandstone" but which Arditto (1972) formally named the *Doona Sandstone Member*.

The clasts in the coarser grained clayrocks vary from brecciated to well-rounded and, whereas the majority are devoid of internal characteristics, a few have relict volcanic textures. The kaolinite matrix frequently comprises small, rounded kaolinite clasts with minor amounts of silt-size quartz and sporadic coal fragments. In contrast, the "special claystone" is composed of elongated masses of fine-grained kaolinite with numerous, smaller rounded aggregates that resemble the "graupen" of the European kaolinite tonsteins (Guthorl et al., 1956), set in an abundant kaolinite matrix. Many of the elongated masses terminate in frayed or "fish tail" edges and mostly they appear isotropic although some are composed of parallel-aligned kaolinite microlites and have the optical properties of a single crystalline mass (Loughnan and Corkery, 1975). These elongated masses are believed to represent intraclasts derived from the reworking of overbank accumulations.

The Doona Sandstone Member, although lacking the lateral extent of the kaolinite clayrocks, has been traced over an area of nearly 500 km$^2$ between Bong Bong (G.R. 257057) and Merrygoen (Higgins, 1971; Arditto, 1972; Corkery, 1973; Callender, 1974). It is light-coloured, fine- to medium-grained and composed of angular quartz grains, chert fragments and kaolinite clasts bonded by a kaolinite matrix. Crossbedding, animal trails, ripple marks and rootlet casts are common and presumably the deposit represents a point-bar accumulation.

The "special claystone" bed and the Doona Sandstone Member are well exposed in a series of quarries near the upper reaches of Dinnykymine Creek (G.R. 233067) where the formation has a thickness of 4 to 5 m, but at "Langdon" (G.R. 239069), 6 km to the northeast of this area, the sandstone is absent and the claystone grades upward almost imperceptibly into the base of the overlying Digilah Formation. At the latter exposure the Ukebung Formation is 4.9 m thick and the kaolinite clayrocks below the "special claystone" are contaminated by appreciable amounts of silt-size quartz and, toward the base, illite becomes progressively more abundant.

At "Berowra" (G.R. 249054) the Doona Sandstone Member is about 2.5 m thick and is underlain by nearly 2 m of dense kaolinite clayrock, the remainder of the section being obscured by soil and talus. However, 9 km to the east near the upper reaches of Bong Bong Creek (G.R. 258050), the Ukebung Formation has overlapped the Wallingarah Formation and rests directly on the Wollar Sandstone. In the latter area the Doona Sandstone Member is reduced to about 0.4 m thick and whereas the clayrocks immediately underlying the sandstone are dense and light-coloured with sporadic worm burrows, they grade downward into dark coloured material containing coaly bands and abundant plant remains.

Fragments of dark coloured kaolinite clayrock associated with blocks of cannel coal were found in the bed of a tributary of Miangulliah Creek, 6 km north of Bong Bong Creek (G.R. 257057) and significantly, Jones (1920) described an occurrence of "coal and shale" underlying the Pilliga Sandstone at this locality. A thorough search of the area however, failed to reveal an exposure of the Ukebung Formation.

Farther to the east and extending into the northwestern sector of the Sydney Basin, the clayrocks of the Ukebung Formation grade into illitic and quartzose sediments making recognition of the unit difficult. Moreover, at Farr's Hill (G.R. 264021), 15 km southwest of Uarbry, the renowned Talbragar fish- and plant-bearing porcellanites occur at approximately the stratigraphic interval of the Ukebung Formation and it would appear that in this area the kaolinite clayrocks of the Ukebung Formation have been replaced by cherty sediments.

Nevertheless, at "Rothbury" (G.R. 313015), 11 km southwest of Merriwa, Harbison-A.C.I. Pty. Ltd. sank a bore through more than 8 m of quartzose kaolinite clayrock containing several coaly

bands and in places, abundant leaf impressions. Part of this sequence is exposed in a cutting along the Merriwa-Wollar road (G.R. 312016).

In the vicinity of Cobborah the Ukebung Formation has apparently undergone a similar facies change. This is evident from the results of extensive shallow-hole drilling carried out by Australian Consolidated Industries Pty. Ltd. (Pollington, 1973) near Medway (G.R. 213028), southwest of Cobborah, where intermittent beds only of kaolinite clayrock were encountered, and also from the investigations of Bell (1973) northeast of Cobborah where the only evidence of the clayrocks is the presence of blocks and clasts of kaolinite within a relatively persistent quartzose sandstone. This sandstone can be observed in a quarry to the side of the Boomley-Cobborah road (G.R. 217036).

Near Boomley, however, and extending along both sides of Boomley Creek and also the western bank of the Talbragar River to beyond Ballimore, the kaolinite clayrocks are reasonably well exposed. In this area the Doona Sandstone Member is absent and the clayrocks are mostly coarse grained although dense material somewhat resembling the "special claystone" of the Merrygoen area, is evident in places while coal seams and sporadic sandstone and ironstone lenses are relatively common.

In the rail cutting immediately north of Boomley (G.R. 205038) and also in the creek bed 400 m farther to the north, 2.5 m of kaolinite clayrock are exposed but in the CH4 Bore (G.R. 201034) of Australian Consolidated Industries Ltd., located 6 km southwest of Boomley, Pollington (1973) recorded a thickness for the formation in excess of 10 m.

At Riley's Gully (G.R. 196027), situated on the western bank of the Talbragar River, 1.5 km west of Elong Elong, two coal seams, each between 1 m and 2 m thick and separated by 8 m to 9 m of strata, occur within the Ukebung Formation. These seams were explored by shafts in the early part of this century (Carne and Morrison, 1915) but, mainly because of high ash contents, exploitation was limited. The shafts have since been filled but from examination of the spoil, it is apparent that the coal is intimately associated with kaolinite clayrocks. The numerous claystone bands shown in the sections of the seam by Carne and Morrison (1915) are probably also of kaolinite clayrock and hence, correspond to the European tonsteins.

About 11.5 km southwest of Riley's Gully the Talbragar River has cut an escarpment into the side of Ballimore Hill (G.R. 182021) exposing the uppermost 12 m of the Ukebung Formation as well as a complete section of the overlying Digilah Formation. The Ukebung Formation in this area consists mostly of interbedded kaolinite clayrock and coal but, more massive beds of coarse-grained clayrock frequently contaminated by siderite, are also present and toward the base of the exposure tend to predominate. The full extent of the clayrocks is unknown but from the logs of the two bores put down in the 1880's (Carne and Morrison, 1915), it is apparent that the Ukebung Formation has thickened appreciably in this area. Lloyd (1935) estimated the combined thickness of the Ukebung and Digilah Formations (the Ballimore Coal Measures) in these bores at 71.7 m and since the Digilah where exposed, measures 28.5 m, the Ukebung must be of the order of 43 m. Nevertheless, there is evidence that some of the coal in the Ukebung Formation has been burnt and possibly the anomalous thickness calculated by Lloyd is attributable in part to collapse of superimcumbent strata. Dulhunty (1973) separated the lower part of this succession in this area and designated it the Ballimore Formation but, since these rocks appear of the same facies as the overlying material, such subdivision would seem unwarranted.

Arditto (1972) traced the Ukebung Formation, including the Doona Sandstone Member, north of Merrygoen to Butheroo Creek but beyond that area the sandstone is apparently absent and outcrops of the clayrocks tend to be poor. Nevertheless, near the intersection of the Mooren and Merrygoen-Binnaway roads, 7 km north of Nielrex (G.R.229079), the formation is exposed over a wide area. Here the clayrocks are relatively coarse-grained and greenish due to partial replacement of aluminium by chromium in the octahedral part of the kaolinite lattice. Another interesting feature of the clayrocks in this area is the presence of particularly well-rounded quartz pebbles, 5 to 10 cm in diameter. A bore put down by Harbison - A.C.I. Pty. Ltd. 500 m southeast of the road intersection penetrated about 11 m of kaolinite clayrock much of which is coarse grained and is associated with coaly stringers.

Coarse grained kaolinite clayrocks also crop out on the side of a small hill adjacent to the railway line 1.8 km south of Binnaway (G.R.233094) where exploration by bore holes has again proven a considerable thickness for the Ukebung Formation (Loughnan, 1971).

The source of the kaolinite for the Ukebung Formation is unknown at present. Possibly as Dixon (1974) suggested, soils developed on the Garrawilla Volcanics supplied the detritus but positive evidence to this effect is lacking.

Digilah Formation

The Digilah Formation, which conformably overlies the Ukebung Formation, is farther removed from and has been less influenced by the basement topography than any of the preceding stratigraphic units. As a result, the thickness and lithology tend to be somewhat more uniform. Nevertheless, outcrops are mostly poor and, like those of the Wallingarah Formation, are generally marked by ferruginous debris. Consequently, where the Ukebung Formation is absent, recognition of the Triassic-Jurassic boundary is difficult.

The formation varies in thickness from 20 to 30 m and is composed mainly of shales and ironstone lenses indicative of a backswamp environment, with sporadic thin beds of sandstone and kaolinite clayrock (Higgins & Loughnan, 1973). Worm burrows, plant and carbonaceous fragments and fossil tree stumps (Arditto, 1972) have been found in the shales.

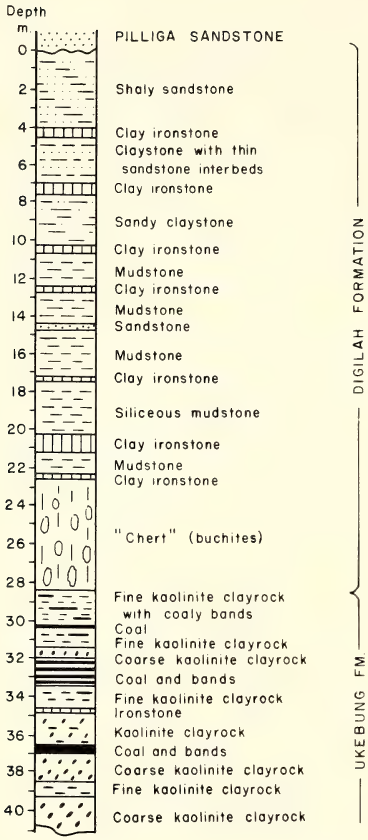


Fig. 3. Section of the Digilah Formation and upper part of Ukebung Formation at Ballimore Hill.

Near the base of formation the shales are predominantly kaolinitic but higher in the sequence, quartz is more abundant and illite is frequently present. An exception to this trend is apparent at "Langdon" (G.R. 239069) where kaolinite constitutes the bulk of the shales and claystones immediately underlying the Pilliga Sandstone. Moreover, at the Ballimore Hill exposure (Fig. 3) the lowermost 5 m of the formation consist of remarkably hard, white to pink "cherts". Examination of these rocks by X-ray diffraction, petrographic and chemical means has revealed that cristobalite is the dominant mineral constituent with mullite, quartz and glass, and apparently they represent sediments that have been subjected to elevated temperatures, probably in excess of 1000°C, brought about by the burning of coal seams in the upper part of the Ukebung Formation. Similar buchite-like rocks have been described previously from the Early Permian Greta Coal Measures of the Hunter Valley (Loughnan and Craig, 1961; Loughnan, 1973). Unlike the latter however, the cristobalite in the "cherts" at Ballimore Hill has the X-ray diffraction pattern of the *beta* form, which is generally believed stable only at temperatures above 275°C whereas below 210°C it should invert instantaneously to the *alpha* form. Nevertheless, according to Florke (1955), *alpha* cristobalite that has formed in the presence of certain ions, frequently develops a disordered structure which has an X-ray diffraction pattern similar to that of *beta* cristobalite but, after heating at 1200°C for several days, the true pattern for the *alpha* form should develop. Possibly the mineral in the "cherts" at Ballimore Hill is disordered *alpha* cristobalite although the X-ray pattern lacks the diffuseness that generally characterises disordered structures and, furthermore, the thermal treatment recommended by Florke failed to produce a detectable change to the mineral.

Most of the kaolinite clayrocks in the Digilah Formation are fine-grained and occur in thin persistent beds, which, although not associated with coal, are remarkably similar in texture, composition and structure to the kaolin coal-tonsteins (Burger et al., 1962) of the Westphalian Coal Measures of Europe. They are well-exposed in the rail cutting at Merrygoen (G.R. 217061) and also on the southern side of the Bullinda inlier (G.R. 244064).

Pilliga Sandstone

An eroded surface separates the Digilah Formation from the overlying Pilliga Sandstone, which resembles the Triassic Hawkesbury Sandstone of the Sydney Basin in that not only does it comprise massive and crossbedded quartzose sandstone with quartz-pebble conglomerate and sparse siltstone and shale but furthermore, in places it contains appreciable amounts of dickite (Arditto, pers. comm.). Ferruginous beds are not uncommon in the unit and between Dubbo and Gilgandra, to the west of Ballimore, fossil lateritic soils that were once worked for ochre, are interbedded with the sandstones.

In the Merriwa-Binnaway-Ballimore area the maximum thickness is probably 100 m but the formation is known to thicken appreciably to the north-west where it forms the main aquifer for the eastern part of the Great Artesian Basin (Mulholland, 1944).

PALYNOLOGY

Wallingarah Formation

Fossiliferous samples of the Wallingarah Formation were obtained from Newbolds General Refractories' DH3 Bore (G.R. 218062) at a depth of 18.69 m from the collar of the bore (i.e. 0.36 m below the base of the Ukebung Formation) and also from the exposure on the northern bank of Butheroo Creek at "Langdon" (G.R. 239067) at about 6 m above the level of the creek where the material is unusually fresh. Both samples contain diverse and essentially similar microfloral assemblages (Table 2) that are characteristic of Triassic associations in Australia generally and which have been variously termed the *Pteruchipollenites* Assemblage by Balme (1964), the palynological unit Tr3 by Evans (1966) and the Ipswich Microflora by Dolby & Balme (1976).

de Jersey (1968, 1970) and de Jersey & Hamilton (1967) have documented Triassic assemblages from bore cores in the Bowen Basin in terms of their distribution between gross lithostratigraphic units, the Rewan Formation, the Clematis Sandstone and the Moolayember Formation. The stratigraphic ranges in Queensland for the forms identified in the Wallingarah Formation are summarised in Table 2 and it will be observed that despite the absence or near absence of *Leiotriletes* spp., *Aratrisporites* spp. and *Osmundacidites* spp., the association of abundant *Alisporites australis*, very rare forms of striate saccate pollen and rare *Lophotriletes novicus*, *Accinctisporites ligatus*, *Rugulatisporites trisinus*, *Chordasporites australiensis*, *Tigrisporites playfordii*, *Foveosporites mimosae*, *Nevesisporites limatulus* and *Duplexisporites* sp. of *D. gyratus* favour correlation of the Wallingarah Formation with the Upper Clematis Sandstone or Lower Moolayember Formation. On the other hand, the presence of *Gutheorlisporites cancellosus* suggests a somewhat older age for the Wallingarah Formation, that of the Clematis Sandstone at the youngest. But, this species is present in the Brady Formation at Poatina, Tasmania (Playford, 1965) and also in the Leigh Creek sequence (Playford & Dettmann, 1965), both of which are younger than the Moolayember Formation of the Bowen Basin (de Jersey, 1975; Dolby & Balme, 1976) and hence, the species would appear of dubious correlative value. Similarly, *Indospora clara* appears to be confined to the Clematis Sandstone or older beds. However, de Jersey (1972) recorded the presence of this species in the Esk Beds, which he regarded as correlatives of the Moolayember Formation. Furthermore, Helby (1970) described an association of *Indospora clara* with *Cardagasporites senectus*, which de Jersey & Hamilton (1967) failed to find in strata below the Moolayember Formation. It should also be noted that the Wallingarah assemblage contains a specimen of the genus *Annulispora* that apparently is absent from the Moolayember Formation (de Jersey & Hamilton, 1967) but rather makes its first appearance in the younger Ipswich Coal Measures of the Moreton Basin.

The Wallingarah Formation therefore, correlates reasonably well with the Upper Clematis Sandstone or Lower Moolayember Formation of the Bowen Basin, an interval which de Jersey (1968, 1970, 1972) considered from comparison with European microfloral assemblages, referable to the Early Anisian (Early Middle Triassic). Consequently this age has been assigned to the Wallingarah Formation.

A similar or at least compatible conclusion may be reached by comparison of the microfloral assemblages of the Wallingarah Formation with those from Triassic strata in the Carnarvon Basin, Western Australia. Thus, the presence of abundant *Alisporites (Falcisporites)*, rare striate pollen and *Tigrisporites playfordii* in the Wallingarah Formation are certainly suggestive of the *Tigrisporites playfordii* Zone of the Carnarvon Basin that, according to Dolby & Balme (1976), based on conodont evidence, ranges through "much of the Smithian, all of the Spathian and probably part of the Anisian stages".

However, the assemblage obtained from the

TABLE 2

MICROFLORA FROM THE WALLINGARAH FORMATION

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| SPORES | | | | | | | |
| * *Annulispora* sp. | + | | | | | | |
| *Apiculatisporites* sp. | + | | | | | | |
| *Aratrisporites* sp.cf. *A. granulatus* | + | + | | | | | |
| *Biretitriletes* sp. | | + | | | | | |
| *Calamospora tener* | + | + | | + | + | | |
| *Calamospora* sp. | + | + | | | | | |
| *Converrucosisporites* sp. | | + | | | | | |
| *Cyathidites breviradiatus* | + | | | | | | |
| *Cyathidites minor* | + | + | | | | | |
| *Dictyophyllidites mortoni* | + | + | | + | + | + | + |
| **Duplexisporites* sp.cf. *D. gyratus* | | + | | | | | + |
| **Foveosporites mimosae* | + | + | | | + | + | + |
| **Gutheorlisporites cancellosus* | + | + | + | | | | |
| **Indospora clara* | + | + | | | | | |
| **Lophotriletes novicus* | + | + | + | + | | | |
| *Matonisporites* sp. | | + | | | | | |
| *Neoraistrickias* | | + | | | | | |
| **Nevesisporites limatulus* | + | | | | | | |
| *Osmundacidites* spp. | + | + | | | | | |
| *Polypodiisporites ipswichiensis* | + | + | | | | | |
| *Punctatisporites* sp. | + | + | | | | | |
| *Retitriletes* sp. | + | | | | | | |
| *Retusotriletes praetexta* | + | | + | | | | |
| **Rugulatisporites trisinus* | + | + | | + | + | | |
| *Rugulatisporites* sp. | + | | | | | | |
| *Stereisporites* sp. | + | + | | | | | |
| *Tigrisporites playfordii* | | + | | | | | |
| POLLEN | | | | | | | |
| **Accinctisporites ligatus* | + | ? | | | + | + | + |
| **Alisporites australis* | C | C | | | | | |
| **Chordasporites australiensis* | + | + | | + | + | + | + |
| *Cycadopites nitidus* | + | + | + | + | + | + | + |
| *Platysaccus queenslandi* | + | + | | + | + | + | + |
| *Protohaploxypinus jacobii* | + | | + | | + | | |

* Species relevant to stratigraphic age.
C = common

1 Wallingarah Formation - Newbolds General Refractories' DH3 Bore.
2 Wallingarah Formation - exposure at "Langdon".
3 Rewan Formation )
4 Clematis Sandstone )
5 Lower Moolayember Formation) Bowen Basin
6 Middle " " )
7 Upper " " )

Wallingarah Formation correlates with the classical Triassic sequence of the Sydney Basin only in the broadest terms. Based on the work of Helby (1970, 1973), the Wallingarah microfloral association has a range within the *Aratrisporites parvispinosus* Assemblage Zone, which includes the Hawkesbury Sandstone and Wianamatta Group. Critical forms are

*Nevesisporites limatulus*, which is not recorded above the Ashfield Shale, and *Rugulatisporites trisinus* and *Annulispora*, which first appear in the Bringelly Shale. Based on these forms, the sampled horizons within the Wallingarah Formation correlate with about the boundary between the Ashfield and Bringelly Shales, but additional comparative data are necessary for more positive identification.

Bourke & Hawke (1977) have demonstrated the northward extension of the shaly facies of the Wallingarah Formation in the Coonamble Embayment and the Gunnedah Basin where it is overlain by unnamed formations all of which according to Morgan (1975a, 1975b, 1975c, 1976a, 1976b) represent the *Aratrisporites parvispinosus* Assemblage Zone. Bourke & Hawke (1977) believe that this zone thickens gradually northward from about 170 m at Weetaliba to near 490 m at Moena. It seems probable therefore, that the distribution of rock types within the *A. parvispinosus* Assemblage Zone is a function of regional facies variation within a progressively subsiding basin.

Ukebung and Digilah Formations

Representative samples of the Ukebung and Digilah Formations were obtained for palynological examination from the Newbolds General Refractories' D.H.3 Bore (Fig. 2) at depths of 6.93 m, 11.58 m, 12.29 m and 15.09 m (Table III) below the collar of the bore. Unfortunately, those from the Ukebung Formation at th- 11.58 m and 15.09 m levels contained abundant amorphous organic debris and only a limited variety of forms, the most prevalent being *Classopollis* spp. and bisaccate pollen. However, the microflora in the sample at 12.29 m, which is of a finely pelletal and carbonaceous claystone located about the middle of the formation, proved both prolific and well-preserved. The assemblage which is also characterised by *Classopollis* spp. and bisaccate pollen, includes very rare *Callialasporites segmentatus*, *Araucariacites fissus*, *Trisaccites variabilis* and *Polycingulatisporites crenulatus*.

A sample obtained from the base of the Digilah Formation in this bore also contains *Classopollis* spp. and *Callialasporites segmentatus* and indeed, the assemblage differs little from that representative of the Middle Ukebung Formation.

The microfloral sequence observed in the samples from the Ukebung and Digilah Formations is typical of assemblages recorded from about the J1/J2 palynological boundary in central Queensland (Evans, 1966) and places these units as equivalent to either the top or a little above the *Nevesisporites vallatus* Subzone of Reiser and Williams (1969) and the *Trisaccites variabilis* Zone of de Jersey (1975). According to de Jersey this interval is Toarcian (Early Jurassic) in age.

From examination of microfloral associations in the northern part of the Coonamble Embayment of the Surat Basin, Morgan (1974, 1976a) and Bourke & Hawke (1977) found the earliest Jurassic strata resting directly on Triassic rocks, to be equivalent to the J3 zone and hence, the Ukebung Formation is apparently the oldest Jurassic stratigraphic unit yet encountered in the embayment. Possibly the depositional basin giving rise to the Ukebung and Digilah Formations extended farther southward across or at least toward the centre of the Sydney Basin since Branagan et al. (1976) have recorded the presence of spore-bearing inclusions of Lower Jurassic strata in diatremes intruding the Sydney Basin sediments.

The Ukebung Formation is approximately equivalent in age to the Boxvale Sandstone Member of the Evergreen Formation of the Surat Basin in Queensland (Evans, 1966; Exon, 1974). The Boxvale Sandstone is a basin-margin, shoreline system, which is correlatable with a distinctive complex of oolitic chamosite horizons (the Westgrove Ironstone Member) of shallow, standing-water facies that

TABLE 3

MICROFLORA FROM THE UKEBUNG AND DIGILAH FORMATIONS

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| SPORES | | | | |
| *Annulispora folliculosa* | + | | | |
| *Antulsporites varigranulatus* | + | | + | |
| *Baculatisporites comaumensis* | + | | | |
| *Biretisporites modestus* | | | + | |
| *Cadargasporites* sp. | + | | | |
| *Cyathidites minor* | + | | + | |
| *Dictyophyllidites mortoni* | | | + | |
| aff. *Granulatisporites* sp.A | + | | | |
| *Neoraistrickia elongata* | | | + | |
| *Neoraistrickia suratensis* | + | | | |
| *Neoraistrickia* sp. | + | | + | |
| *Osmundacidites wellmanii* | | | + | |
| *Perinopollenites elatoides* | + | | | |
| *Polycingulatisporites crenulatus* | | | + | |
| *Retitriletes austroclavatidites* | + | | + | |
| *Retitriletes huttonensis* | | | + | |
| *Retitriletes* spp. | + | | | |
| *Steriisporites antiquasporites* | + | | | |
| POLLEN | | | | |
| *Alisporites lowoodensis* | + | | + | |
| *Alisporites* spp. | C | C | C | C |
| *Araucariacites australis* | | | + | |
| *Araucariacites fissus* | + | | | |
| *Callialasporites segmentatus* | + | | + | |
| *Classopollis* spp. undiff. | VC | VC | VC | VC |
| *Cycadopites nitidus* | + | | | |
| *Indusiisporites parvisaccatus* | + | | | |
| *Trisaccites variabilis* | + | | | |
| *Vitreisporites pallidus* | + | | | |
| ALGAE | | | | |
| aff. *Pyritella* | | | + | |
| *Quadrisporites* sp. | | | + | |

VC = very common. C = common.

1 Digilah Formation - 6.93 m below collar.

2 Ukebung Formation - 11.58 m below collar.

3 Ukebung Formation - 12.29 m below collar.

4 Ukebung Formation - 15.09 m below collar.

extend across the Surat Basin and are also evident in the Nambour Basin (R.J. Paten-pers.comm.). Closely associated with this complex are occurrences of acanthomorphic acritarchs, which provide useful marker fossils for this horizon in the subsurface (Evans & Terpstra, 1962; Reiser & Williams, 1969).

Although the characteristic acritarchs of the Surat Basin were not found in samples from either the Ukebung or Digilah Formations, the microfloral assemblages extracted from these units do contain relatively common micro-organisms referable to *Quadrisporites* and other unicellular algal types. The precise biological classification of *Quadrisporites* in particular, and its habitat have not been determined with certainty. It has been found in diverse strata of varying ages, but nevertheless, it appears to have flourished in standing lacustrine waters.

Discussion

It is apparent therefore, that since the Wallingarah Formation is referable to the Anisian and the Ukebung Formation to the Toarcian, a hiatus of about 30 m.y. (Eysinga, 1975) separated deposition of the two units, and significantly, Exon (1973) has recorded the presence of a diastem of similar age and duration separating Triassic and Jurassic strata along the western margin of the Surat Basin in Queensland. During this interval the Garrawilla Volcanics were extruded as is evident at Binnaway where they rest on the Wallingarah Formation and in turn, are overlain by the Ukebung Formation. However, Dulhunty and McDougall (1960) and Dulhunty (1972) have determined isotopic dates for the Garrawilla Volcanics ranging from 171.5 m.y. to 201.5 m.y., that is from Norian (Middle Late Triassic) through to Bajocian (Early Middle Jurassic). Consequently, extrusion of the volcanics not only preceded deposition of the Ukebung Formation but furthermore continued for some time after laying down of the Digilah Formation.

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# Early East-Southeast Trending Folds in the Sofala Volcanics, New South Wales

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ABSTRACT. A regional interference-fold pattern has been discovered in the Ordovician Sofala Volcanics by tracing out mappable chert bands. The interference pattern results from superposition of meridionally - trending folds on an early east - southeast trending set of structures. The early folds are restricted to the Sofala Volcanics whereas the meridional folds affect all pre-Upper Carboniferous rocks in the region. The geometry of the early folds is determined in part by restoring the folded unconformity at the base of the Upper Devonian Lambie Group to the horizontal. The early folds were possibly formed in the latest Ordovician and/or Early Silurian, before the Lower Silurian Tanwarra Shale was deposited.

## INTRODUCTION

Recent mapping of the Upper Ordovician Sofala Volcanics in the northeastern Lachlan Foldbelt (Fig. 1) has revealed a complex fold interference pattern (Fig. 2; Gilfillan, 1975, 1976). This fold pattern is unknown in the bulk of the Siluro-Devonian Hill End Trough sequence, which has been deformed into meridional structures (Packham, 1968*a*; Hobbs and Hopwood, 1969). The meridional structural grain is found in all rocks older than Late Carboniferous, and is the result of the major latest Devonian to Early Carboniferous folding of the region (Powell *et al.*, 1977). The interference pattern in the Sofala Volcanics is thus likely to have been produced by the superposition of meridional folds on earlier structures, and in this note we examine the geometry of these early structures and the constraints on their age.

## STRUCTURE OF THE SOFALA VOLCANICS

The key to the structure of the area is provided by two prominent chert bands, each several hundred metres thick, which have been traced across the area (Fig. 2). These marker bands, first recognised in the north - central part of the area by Cas (1969), separate volcanic arenites and rudites that form the bulk of the formation (Gilfillan, 1976). The upper chert band, especially, can be walked out with little difficulty, although in the northwestern part of the area the mesoscopic structure is very complex. In map view, the meridional folds have straight axial traces whereas the other folds are curved, thus confirming the inference from regional considerations that the meridional folds are the youngest.

In profile (sections X - X' and Y - Y', Fig. 2), the meridional folds are close, locally tight, and overturned to the east. There is no axial-surface cleavage associated with these, or with the earlier folds in the Sofala Volcanics. In contrast, meridional folds in the Siluro - Devonian Hill End Trough sequence to the west, and in the Upper Devonian Lambie Group to the east, have axial-surface cleavage in pelitic beds. The major meridional structures in the Sofala Volcanics are synformal in the west and antiformal in the east, and the easternmost belt of outcrops is part of the overturned limb of the meridional antiform south of the intrusive andesite.

The early folds have sinuous axial traces, with a regional trend of east - southeast. One major antiform crosses the centre of the map area, and where it intersects the major meridional antiform (near the Turon River, south of the intrusive andesite, Fig. 2), the oldest part of the Sofala Volcanics is exposed. The interference pattern is thus grossly domal, with meridional folds on the southwestern limb of the early anticline plunging southward, in places as steeply as 60°. The complex map pattern of the upper chert band in the northwestern part of the area is the result of the superposition of meridional folds on several early folds of 100 to 500 metre wavelength. Meridional folds in this area, which lies on the northeastern limb of the early anticline, plunge gently north.

## PRE-UPPER DEVONIAN FOLD GEOMETRY

Some aspects of the geometry of the early folds (e.g. the position and orientation of the axial trace of megascopic folds) can be determined by analysing bedding orientations and outcrop patterns in the Sofala Volcanics, but outcrop is

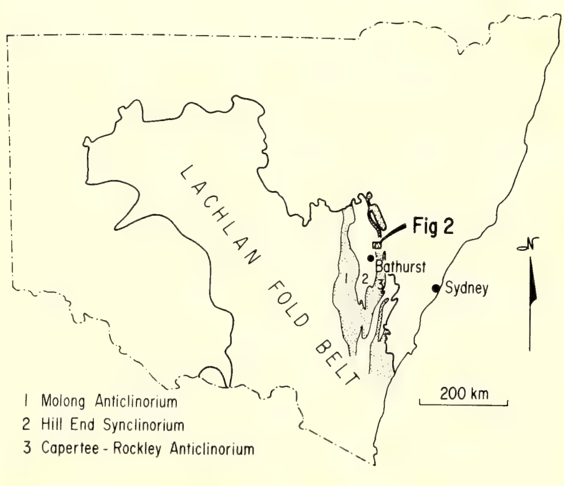



Fig. 1. Structural setting of the area.

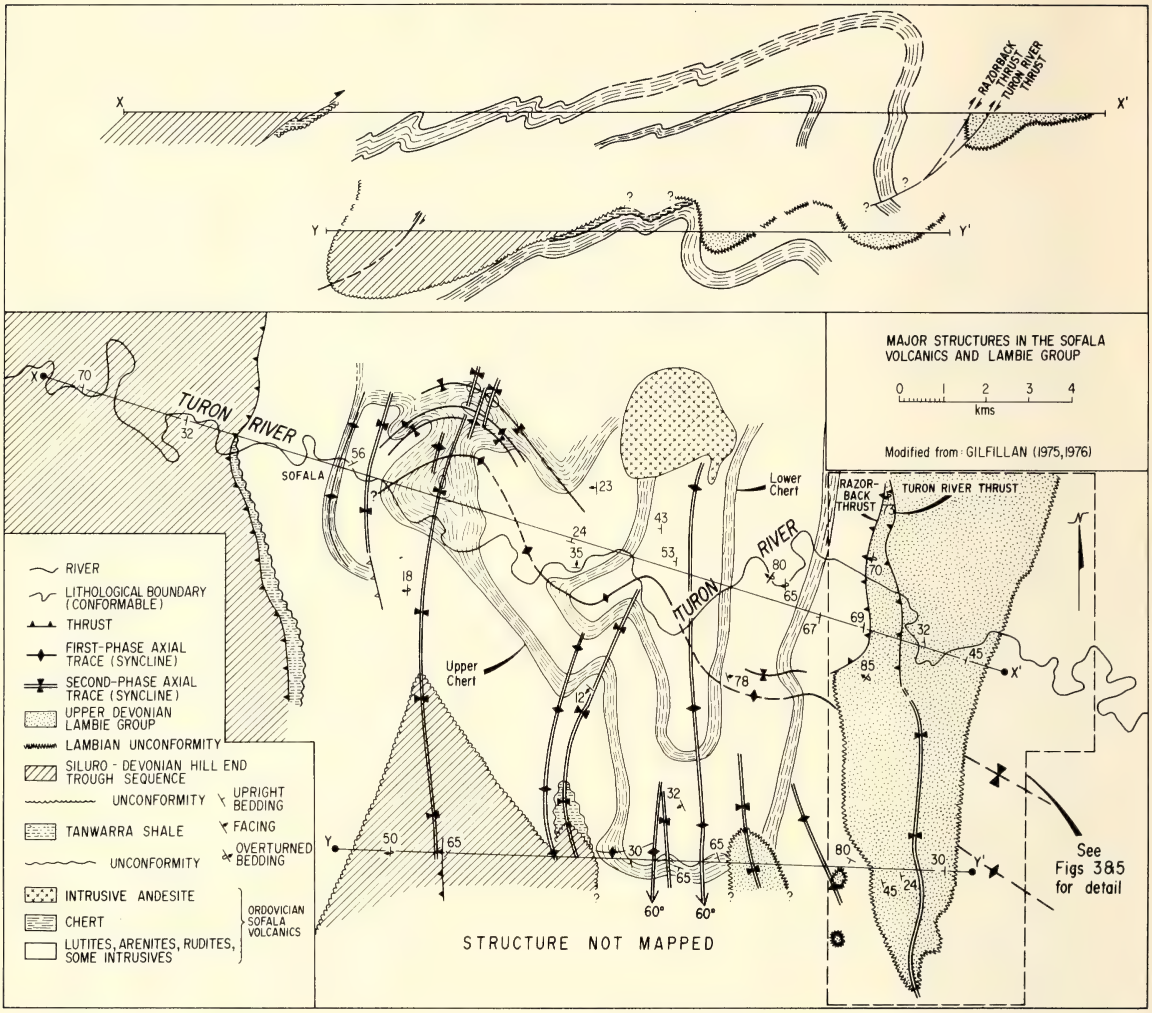
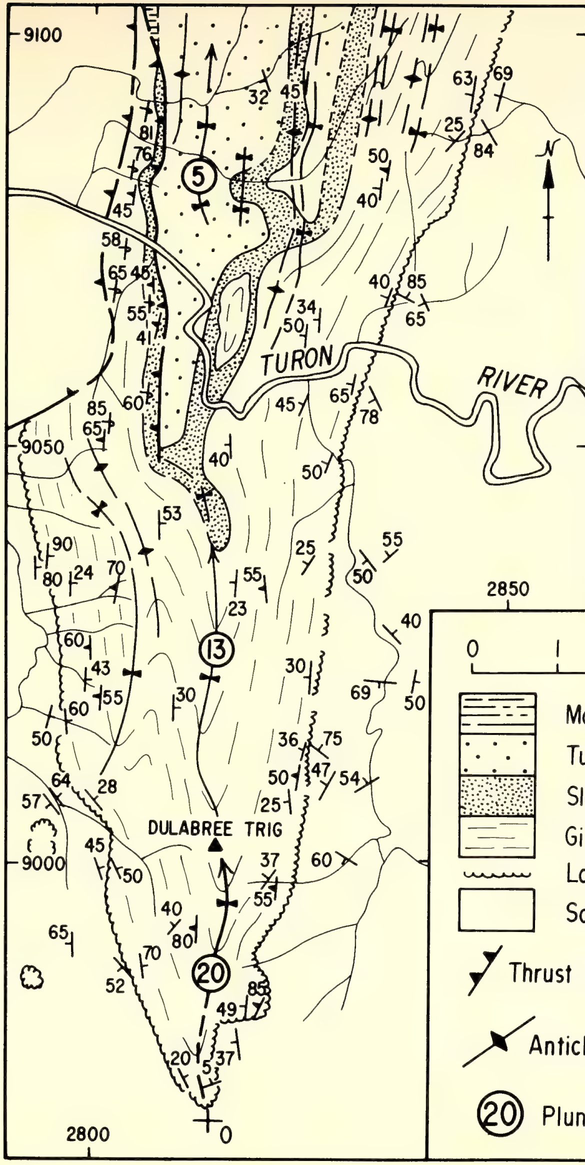


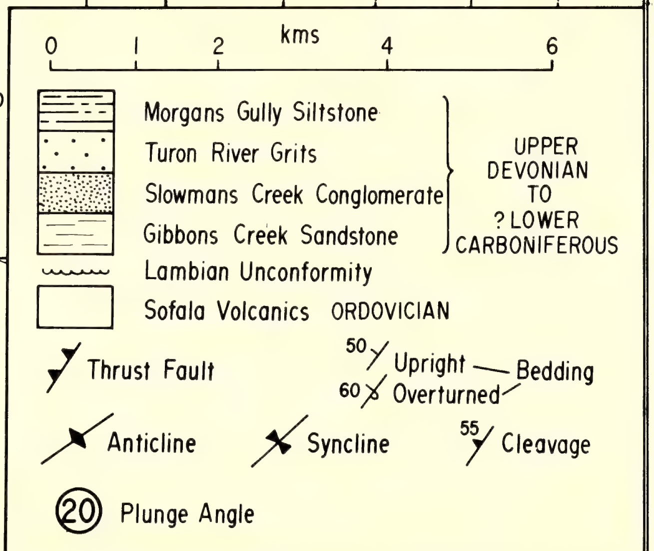

Fig. 2. Structural map and sections through the Sofala Volcanics and adjacent rocks (after Gilfillan, 1975, 1976).

generally not sufficient to permit detailed description of the interference pattern on a small scale. The problem is difficult because no penetrative fabric element unique to either of the fold sets exists, and thus it is difficult to determine to which fold set any particular mesoscopic structure belongs.

In the Mt. Dulabree Syncline at the eastern edge of the area (Figs. 2 and 3), the geometry of the early folds can be determined by removing the effects of the meridional deformation. The Upper Devonian sediments in this syncline have been folded by the meridionally trending deformation, but lack any evidence of east - southeast trending structures. The Upper Devonian Lambie Group was evidently deposited on the Sofala Volcanics after the early folding, and thus the geometry of the early folds can be determined by restoring bedding in the Sofala Volcanics to its pre- Upper Devonian configuration.

The method used is a standard stereographic rotation using as many bedding couplets either side of the Lambian Unconformity as outcrop afforded (Fig. 3, Table). Using the local orientation of the regional meridional fold axis (determined from bedding measurements of the Lambian sediments only), we rotated bedding orientations in the Sofala Volcanics to a pre-fold orientation stereographically by (a) removing the local orientation of the regional fold axis, and then (b) unfolding the residual limb dip on the Lambian beds (Fig. 4). This standard procedure maintains the present angular discordance between beds in the Sofala Volcanics and the Lambie Group. The stereographic technique restores the overlying beds to horizontal, or near horizontal (*See* Appendix), and the underlying beds to their orientation before the Upper Devonian, assuming no ductile strain in the underlying rocks during the later folding. We cannot tell from our limited data whether such an assumption is fully justified, but we note that Powell and Edgecombe (1978), using the same technique found no evidence of strain-




BEDDING COUPLETS ACROSS THE LAMBIAN UNCONFORMITY

| Location | So(U) | So(L) | Regional Fold Axis | Restored So(L) |
|---|---|---|---|---|
| 2845 9092 | 63/280 | 84/261 | 5/358 | 24/251 |
| 2845 9092 | 63/280 | 69/281 | 5/358 | 15/318 |
| 2845 9088 | 25/313 | 84/239 | 5/358 | 71/237 |
| 2835 9067 | 45/254 | 56/297 | 5/358 | 23/338 |
| 2835 9067 | 45/254 | 68/272 | 5/358 | 25/262 |
| 2835 9067 | 40/290 | 85/015 | 5/358 | 87/198 |
| 2832 9057 | 41/281 | 69/238 | 5/358 | 40/218 |
| 2832 9057 | 65/275 | 78/241 | 5/358 | 31/206 |
| 2831 9055 | 60/267 | 90/225 | 5/358 | 55/207 |
| 2828 9035 | 25/305 | 50/222 | 13/004 | 52/205 |
| 2826 9022 | 30/274 | 69/186 | 13/004 | 62/024 |
| 2825 9013 | 35/280 | 75/025 | 13/004 | 80/037 |
| 2825 9009 | 26/281 | 47/297 | 13/004 | 18/297 |
| 2825 9009 | 26/281 | 62/264 | 13/004 | 40/251 |

| Location | So(U) | So(L) | Regional Fold Axis | Restored So(L) |
|---|---|---|---|---|
| 2825 9009 | 26/281 | 54/329 | 13/004 | 32/352 |
| 2824 8997 | 44/290 | 60/210 | 20/004 | 67/194 |
| 2816 8980 | 35/290 | 37/260 | 20/004 | 25/196 |
| 2813 8971 | 25/304 | Horizon. | 20/004 | 30/137 |
| 2804 8986 | 70/086 | 75/150 | 20/004 | 60/169 |
| 2804 8986 | 70/086 | 52/231 | 20/004 | 74/046 |
| 2802 8998 | 50/070 | 45/085 | 20/004 | 8/175 |
| 2802 9002 | 41/059 | 38/095 | 20/004 | 17/160 |
| 2802 9002 | 41/059 | 50/079 | 20/004 | 14/103 |
| 2798 9008 | 41/070 | 64/061 | 20/004 | 25/046 |
| 2798 9008 | 41/070 | 80/230 | 20/004 | 62/040 |
| 2798 9008 | 41/070 | 57/230 | 20/004 | 83/047 |
| 2797 9009 | 30/068 | 75/068 | 20/004 | 42/068 |
| 2797 9009 | 30/068 | 90/070 | 20/004 | 59/068 |
| 2796 9017 | 60/080 | 50/100 | 20/004 | 18/201 |
| 2796 9017 | 60/080 | 55/138 | 20/004 | 47/182 |
| 2794 9036 | 90/095 | 80/080 | 0/004 | 18/326 |

* Locations are eight - figure grid references to 1:250,000 geological map of New South Wales (Packham, 1966). $S_o$(U) and $S_o$(L) refer to bedding in the rocks above and below the Lambian unconformity, respectively. The regional fold axis is determined from data in Henry (1975) and Powell *et al.*, (1977), and the method of restoring $S_o$(L) to its pre-Upper Devonian orientation is outlined in the text.

Fig. 3. Structure of the Mt. Dulabree Syncline and adjacent Sofala Volcanics. Table shows bedding couplets across the Lambian Unconformity used to determine the pre- Upper Devonian structure of the Sofala Volcanics.

induced changes in 130 angular discordances between Upper and Lower Devonian beds across the same unconformity in many other places in the northeastern Lachlan Foldbelt. Modifications caused by strain are probably unrecognizable in the scatter caused by other sources of imprecision (*see* brief discussion in Powell and Edgecombe, 1978).

The result of restoring 31 bedding measurements in the Sofala Volcanics (Fig. 3, Table) to their pre - Upper Devonian orientation is shown in the stereograms and map of Fig. 5. The highly scattered distribution of bedding poles in their present orientation (Fig. 5a), differs strikingly from the girdle-like distribution in their restored pre - Upper Devonian orientation (Fig. 5b). This distribution gives an early fold axis plunging 5° towards 125°. The scatter either side of the girdle may be partly due to various sources of measurement imprecision, but is also due partly to a change in orientation of the early folds around the Mt. Dulabree Syncline. On the eastern limb, 17 restored bedding poles from the eastern limb define a very narrow girdle about an early fold axis plunging 14° towards 285°, whereas 14 restored bedding poles from the western limb define an axis plunging 18° towards 130°. The 40° angular difference between these axes may reflect plunge variation in the pre- Upper Devonian folds, but our data are insufficient to test this explanation.

The map - view axial trace of the early folds agrees well with the pre- Upper Devonian fold axis derived by restoring the Lambie Group to the horizontal. When each bed in the Sofala Volcanics is plotted in its restored pre - Upper Devonian orientation on the map, a number of anticlines and synclines can be recognised. A profile through these folds (Fig. 5, section A - B) shows that the fold - limb divergence is open to locally close. Axial surfaces are upright, except in the southern part of profile AB where they are slightly over - turned towards the southwest.

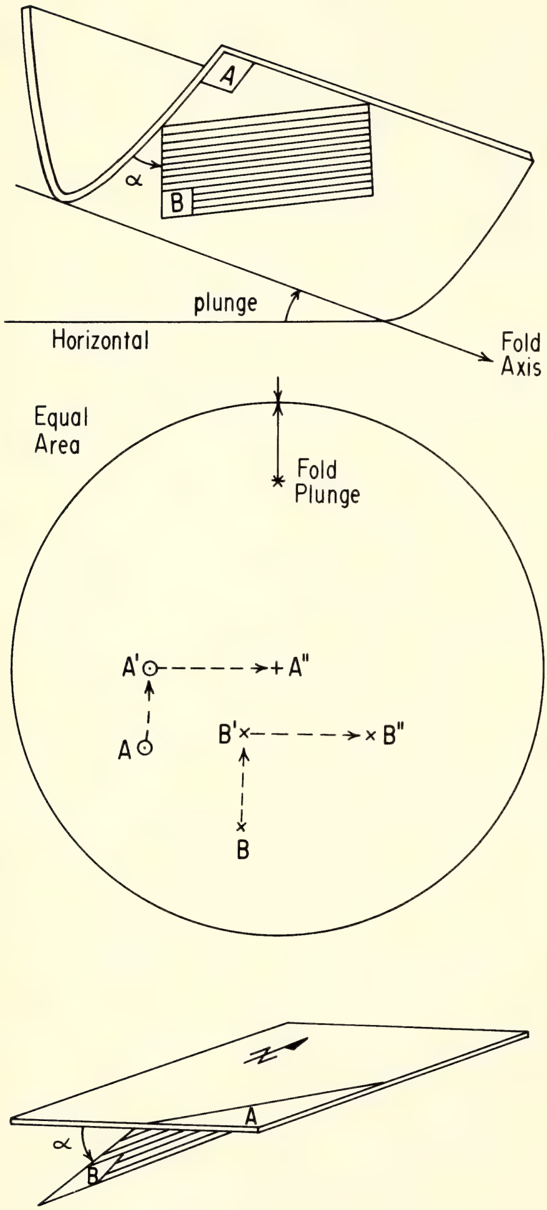



Fig. 4. Stereographic method for restoring the limb of a plunging fold (plane A) and a subjacent plane (plane B) to a pre-fold orientation. Planes A and B rotate along small circles to A' and B', respectively, as the fold plunge is removed, and then B' rotates to B'' around a small circle as A' rotates to the centre of the stereographic net. The initial angle, α, between A and B is maintained throughout the procedure.

## COMPARISON OF THE GEOMETRY OF THE EARLY AND LATE FOLDS

Despite the general difficulty of determining to which group of folds any particular minor structure belongs, Gilfillan (1975) was able to find at least twelve mesoscopic folds that belong to the early set of folds. The late folds are commoner, and their geometry can be determined on a number of scales from outcrop to regional - map scale. Using all the information available, we have compared the geometry of the two fold sets (Table 1).

The early folds are symmetrical and more open in profile than the late folds, but the only criterion which clearly discriminates between the two fold groups is the azimuth of the fold-axis.

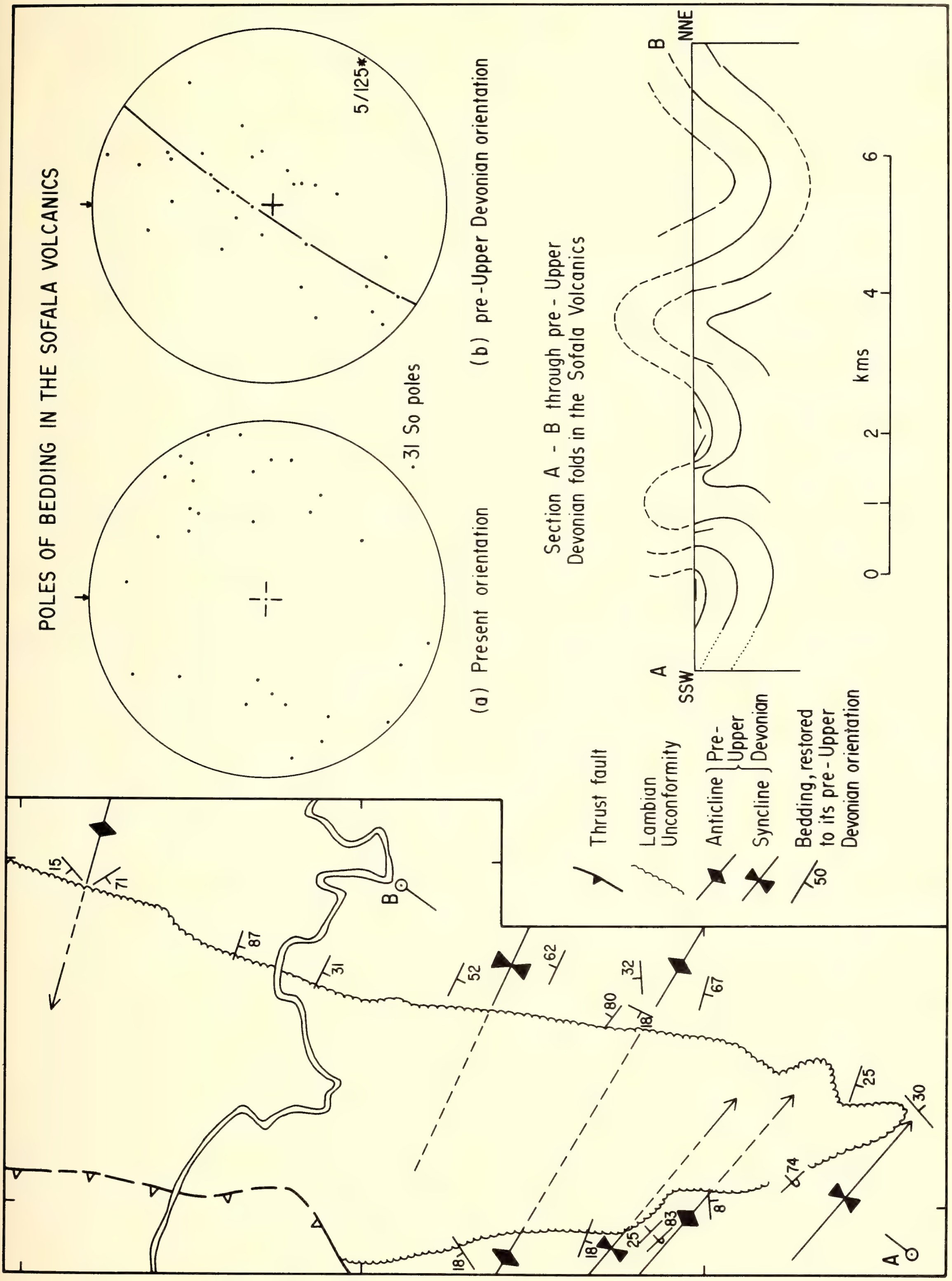



Fig. 5. Pre-Upper Devonian structure of the Sofala Volcanics adjacent to the Lambian Unconformity. (a) and (b) are equal-area stereograms showing the orientation of bedding in the Sofala Volcanics before (a) and after (b) the Lambian beds are restored to horizontal (Fig. 4). AB is a section drawn from the pre-Upper Devonian bedding orientations in the map.

TABLE 1

Comparison of the geometry of mesoscopic and macroscopic early and late folds in the Sofala Volcanics and adjacent Hill End Trough and Lambie sequences. Data from Crook and Powell, 1976; Gilfillan, 1975; Henry, 1975; Hordern, 1973; Willis, 1972.

| Feature | Early Folds | Late Folds |
|---|---|---|
| Distribution | In Sofala Volcanics only | In all pre-Upper Carboniferous rocks |
| Fold-axis | Variable, but regionally trends ESE | Trends within a few degrees of north |
| Fold-axis plunge | Variable at present, but approximately horizontal after removing effects of the late folds | Approximately horizontal in the Hill End Trough and Lambie sequences. Variable in the Sofala Volcanics depending on pre-existing geometry of early folds |
| Axial-surface orientation | Upright to slightly overturned to SW | Overturned, varying from $70^{\circ}$ in the west (Hill End Trough sequence) to $50^{\circ}$ in the east (Lambie Group) |
| Axial-surface cleavage | No | Yes, in the Hill End Trough and Lambie sequences. No in the Sofala Volcanics |
| Fold style | Nearly symmetrical, with limbs of approximately equal length | Commonly asymmetrical, with long upright western limbs and shorter, overturned eastern limbs. Thrust faults commonly developed on the overturned western limbs of synclines |
| Interlimb angle | Open to close | Close to tight |

## CONSTRAINTS ON THE TIMING OF EARLY FOLDING

The early folds postdate deposition of the Sofala Volcanics and predate deposition of the Lambie Group. The folding therefore took place between Gisbornian (Late Ordovician) and Frasnian (Late Devonian) times. Within this span the folds may have formed in the Latest Ordovician or Early Silurian. The older age constraint is from the Gisbornian graptolites (Packham, 1968*b*, p. 115; Cas, 1969) which occur in the lower part of the Sofala Volcanics (Gilfillan's (1976) Unit C ) between the upper and lower chert bands, and mid-Gisbornian to early Estonian conodonts, corals and algae that occur near the top of the Sofala Volcanics (Pickett, 1978). The younger age may be indicated by the age of the Tanwarra Shale (Early Silurian, Packham, 1968*b*), and structural information. First, no east - southeast trending folds are known in the Hill End Trough sequence, which appears to be at least as old as Late Silurian (Packham, 1968*b*). Second, in the central-southern part of the area (Fig. 2), the Tanwarra Shale, folded in one of the late meridional synclines, shows no evidence of ESE - trending structure, and erosionally truncates the Sofala Volcanics to the top of the upper chert band. This information demonstrates that part of the Sofala Volcanics had been uplifted and eroded prior to the deposition of the Tanwarra Shale, and the lack of east - southeast trending structures in the Tanwarra Shale and younger rocks suggests that this uplift may have been associated with the early folding.

Nevertheless, the conclusion that the early folding occurred in the Latest Ordovician or Early Silurian must be treated with some caution,because mapping near Palmers Oaky, some 5 km southeast of the eastern edge of this area (Fergusson, 1976), has demonstrated the presence of east - northeast trending folds in rocks of Latest Silurian to Early Devonian age. The folds near Palmers Oaky are quite similar in many characteristics to those in the Sofala Volcanics, especially in that they lack an axial - surface cleavage and have inclined axial surfaces dipping northwards. If these folds are subsequently shown to be a southeastern continuation of the early folds in the Sofala Volcanics,then the age of all the early folds will be Early or Middle Devonian. There is, of course, no reason why there should not be more than one group of latitudinally trending folds pre - dating the major regional meridional folds.

## STRATIGRAPHIC THICKNESS OF THE SOFALA VOLCANICS

The presence of the chert bands provides two markers from which estimates of the stratigraphic thickness can be made. Gilfillan (1976) estimates that the Sofala Volcanics have an exposed thickness of approximately 1,500 m in the western part of the area, and twice this thickness in the eastern part of the area. The rocks in the eastern outcrops are rudites and arenites coarser than most of those in the west. Because the base of the formation is not exposed, and the top is an unconformity, these stratigraphic thicknesses are a minimum estimate of the original thickness deposited. However, the apparent thickness of 4 km in section XX' (Fig. 2) is greater than the ex-

posed stratigraphic thickness because of repetition caused by parasitic meridional folds, and the orientation of the section nearly parallel to the early fold axis.

## DISCUSSION AND SIGNIFICANCE

The recognition of the east- southeast trending folds in the Sofala Volcanics explains the latitudinal strikes in many parts of the area (*see* Packham, 1968*a*), which are otherwise anomalous in the regional meridional structure. Other areas with bedding orientations apparently incongruous with the regional meridional trends should be investigated to see how widespread latitudinally-trending structures are. Grossly latitudinal folds in Ordovician rocks have been reported in New South Wales from near Albury (Hellman, 1976), and in Victoria from near Tallandoon (Rogerson, 1976) and Mansfield (Hopwood *et al.*, 1977). If these latitudinal folds are all of a similar age, they may reflect early regional structures oblique to the later meridional structural grain. The significance of this observation is discussed elsewhere (Powell *et al.*, in prep.).

## ACKNOWLEDGEMENTS

This work was supported by Macquarie University and Australian Research Grants Committee. Field mapping was carried out by Gilfillan and Henry as part of Honours projects supervised by Powell who subsequently extended and synthesized the data. Gilfillan was partially funded by grants from Western Mining Corporation and Esso Australia Limited. R.S. Powell kindly typed the final manuscript. We thank Ray Cas, Keith Crook, David Feary, Michael Rickard, John Veevers and Ron Vernon, for critical comments on an early manuscript.

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## APPENDIX

In an ideal cylindroidal fold, by removing the fold plunge and then the residual limb dip, one may restore each bed in the fold exactly to the horizontal. Since few natural folds are perfectly cylindroidal, even if statistically cylindroidal, the measured bedding poles generally scatter symmetrically either side of the girdle normal to the fold axis. Thus, when the stereographic procedure described in the text is used, any particular bed may, after rotation, have a residual dip towards one or other of the fold axial trend directions. The whole family of restored beds, however, will be statistically horizontal with as many dipping gently towards one direction as the opposite way. An alternative method of restoring beds to their pre-fold orientation is to make each of the overlying beds rotate exactly to horizontal by assuming an appropriate local fold axis of similar azimuth to, but slightly different plunge angle from, the local orientation of the regional fold axis. The latter procedure transfers all the natural scatter of beds about the bedding-pole girdle to the folds in the underlying rocks. In practice, there is little difference in the resulting stereograms of the restored bedding poles in the underlying rocks, whichever method is used.

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# An Unusual Specimen of Fossil Wood

R. K. Bamber, M. F. Clarke and Peter Jamieson*

ABSTRACT. An unusual fossil wood from the South Coast of New South Wales is described. Although siliceous it was extremely friable. The fossil was composed almost entirely of long filaments which were shown microscopically to be siliceous replicas of the lumina and pit chambers of longitudinal tracheids. It was identified as *Araucarioxylon*.

The process of silicification in relation to the anatomy of the fossil is discussed.

A fossil wood exhibiting an unusual pattern of silicification has been found. The characteristics of this fossil may provide some explanation of the nature of the silicification process of wood.

The fossil was found in Tertiary sediments on the south coast of New South Wales, on the north side of Bannisters Point 5 km north of Ulladulla (G.R.478395, Ulladulla 1:50,000 Sheet 8927-11). It occurs in a quartzite block lying at the back of the sand beach. The block is derived from a cliff cut into an interbedded sequence of flat-lying sandstones, clays and quartzites. The sequence forms part of a small sedimentary basin of which there are a number on the south coast (Hall, 1969; McElroy, 1969). Basalts are associated with this type of sedimentary sequence and at a site 10 km north of Ulladulla they have been dated at 25.9 million years B.P. (Wellman and McDougall, 1974). It seems likely, therefore, that the quartzite is of Oligocene age.

The quartzite is a submature quartz arenite. The detrital quartz grains vary from <0.1 mm to 1.3 mm with an average size of 0.4 to 0.6 mm; they are poorly sorted and subangular to subrounded. Overgrowths are common, the fine-grained quartz filling spaces between grains. Detrital tourmalines and zircons occur in minor amounts. The quartz grains are mainly of plutonic or metamorphic origin with undulose extinction, plus smaller amounts of vein quartz with numerous inclusions and straight extinction. The wood occurred as a cylinder 20 cm long and 8 cm in diameter. The bulk of the cylinder was composed of fibrous, flexible strands of cryptocrystalline quartz, while the outer 4 mm was composed of quite coarsely crystalline quartz with a highly porous fabric.

Superficially the specimen did not resemble a fossil wood as none of the gross structural patterns of wood was visible. It was black in colour and crumbled easily to a powder when handled. Examination with light microscopy revealed that the specimen was composed principally of fibrous or rod-like structures about 20 μm in diameter and exceeding 2.5 mm in length. The rods appeared to have pit-like structures along their length. Ray-like fragments were also present. The appearance of the rods was typical of coniferous longitudinal tracheids.

Examination with scanning electron microscopy showed the pits on the tracheid walls to be bordered, abundant, crowded, arranged alternately in rows of up to three and to be mostly on the radial walls (Figs. 1, 2). The rays were small, about three cells high by one cell wide, and contained two to eight pits per cell. These characteristics are only found in the wood of the family Araucariaceae (Phillips, 1948). Fossil wood with these characteristics has been referred to as *Araucarioxylon* (Coulter and Chamberlain, 1910; Jeffrey, 1917).

Observation with the scanning electron microscope also revealed that the tracheid-like rods were not silicified wood in the normal sense but casts or replicas of the cell cavities, that is, the tracheid lumina and the chambers of the bordered pits. It showed that cell wall and intercellular substance was almost completely absent (Figs. 1, 2). The individual tracheid replicas seemed to be bonded only by connections of siliceous material through the pit apertures or by the ray material. This relatively loose bonding explains the ease with which the fibrous structure could be powdered. Strong evidence that the rods were replicas of the cell cavities is provided by Fig. 2 in which it can be seen that the pit chamber protrudes above the more or less cylindrical rod. The pit apertures are also clearly evident on the pit chamber replicas. The form of the fossil wood is similar to those described as lithomorphs by Leo and Barghoorn (1976) and considered to be siliceous replicas of wood cells. The material illustrated in Figs. 1, 2 differs from that illustrated by Leo and Barghoorn in that it has not been subjected to any preparative treatment other than coating with a conductive material prior to scanning electron microscopy. Their material was either silicified in the laboratory or, alternately, chemically etched and macerated before being prepared for microscopy.

The absence of cell wall and intercellular substance indicates that silicification of this specimen occurred primarily by deposition of silica in the cell cavities before the breakdown and loss of the wood. The loss of the cell wall and intercellular substances occurred at a later period during which, it is presumed, the geological conditions had altered and no longer favoured silicification. It would seem that if the conditions under which the initial silicification

* communicated by S.J.Riley

occurred had continued then the fossil would have undergone complete silicification.

These observations support the hypothesis (Buurman, 1972; Leo and Barghoorn, 1976) that silicification of the cell cavities can proceed independently of silicification of the walls in the following stages: (a) initial infiltration and deposition of silica in the cell lumina and pit chambers, (b) loss of wood, (c) infiltration and deposition of silica in the voids left by the loss of the wood (Fig. 4), a stage not reached by our specimen.

The above observations are in opposition to the hypothesis (Buurman, 1972; Scurfield *et al.*, 1973) that the cell walls are replaced by silica *before* the cell lumina and other cavities become filled with silica deposits. Seeing that initial replacement of cavities rather than cell walls would enhance preservation of cell structure in circumstances where overlying sediments would tend to compress the wood during lithification and that infiltration of siliceous fluid into cell cavities would be dynamically simpler than its penetration of cell walls, it seems that the sequence suggested by Leo and Barghoorn and supported by ourselves is the more likely process for the silicification of wood.

The assistance of Photographic Section of the Forestry Commission of New South Wales in preparing the illustrations is acknowledged.

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FIGURE CAPTIONS

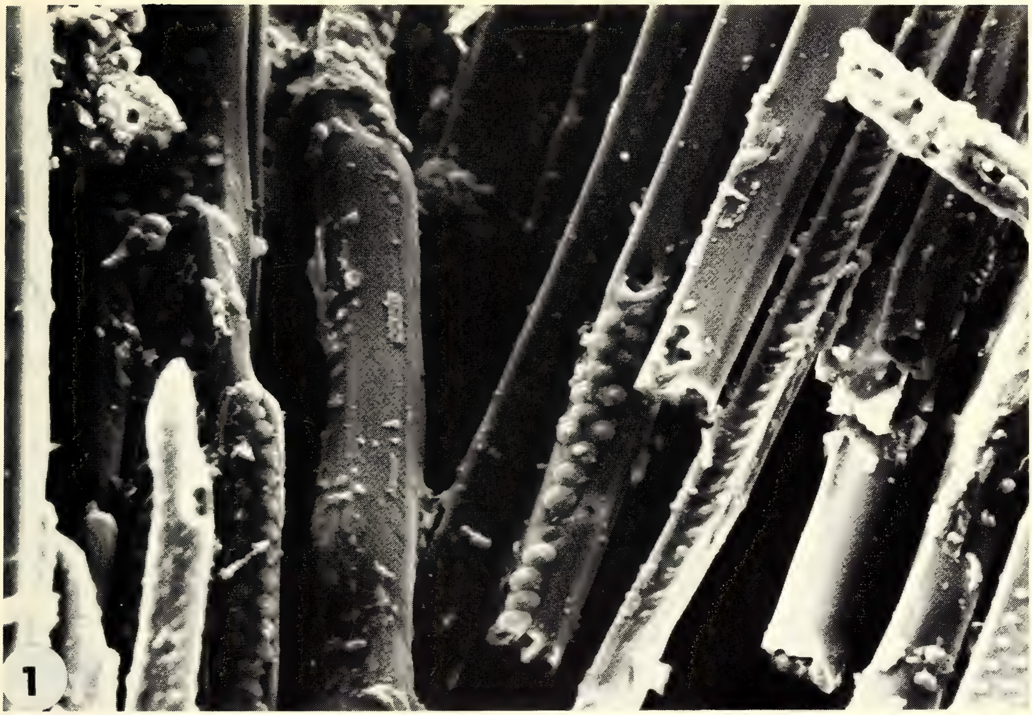
Figs. 1 - 4: Scanning electron micrographs. Specimens coated with carbon and gold/palladium.

Fig. 1: Partially fossilized wood *Araucarioxylon* showing the rod-like siliceous replicas of the longitudinal tracheid lumina. X 630. No cell wall material is present.

Fig. 2: Same as Fig. 1. Showing details of the replicas of pit chambers and portions of tracheid lumina. X3200. A, pit aperture; BP, bordered pit; T, tracheid.

Fig. 3: Surface of contemporary non-fossilized wood of *Araucaria cunninghamii*. The surface has fractured along the middle lamella of the longitudinal tracheids exposing the pit chamber (PC). Portions of some ray parenchyma (RP) cells are present. X1400.

Fig. 4: Surface of completely fossilized wood of *Araucarioxylon*. Portions of longitudinal tracheids and a number of ray parenchyma cells are present. No voids are present. X420.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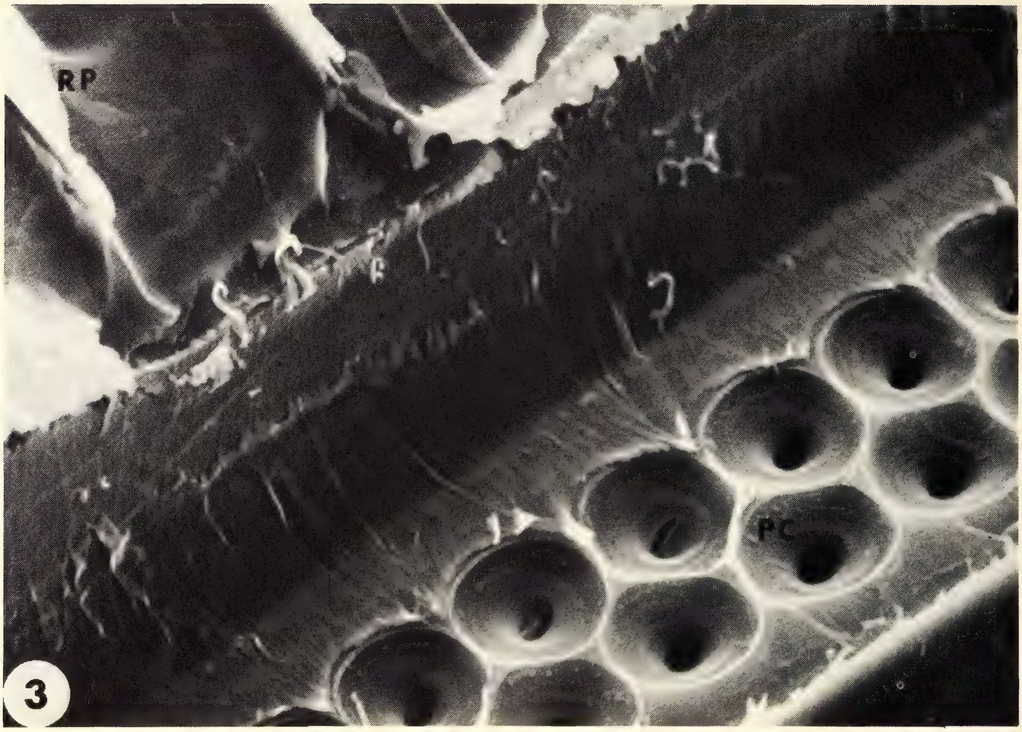
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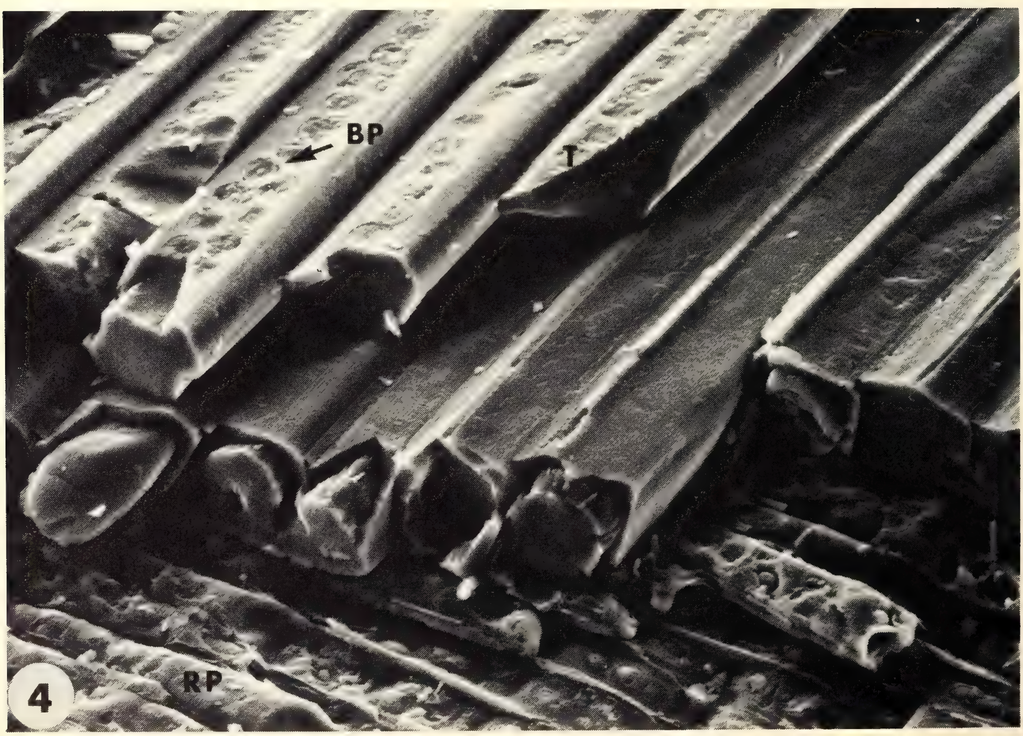
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ADDENDUM:-

In Volume 111 Parts 1 and 2 the affiliation of the authors B.M. Agrawal and Virendra Kumar was inadvertently omitted:-

A q-expansion Formula by B.M. Agrawal and Virendra Kumar
Government Science College,
Gwalior, India.

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# Engineering Geology of Farm Water Storages

F. C. Beavis

ABSTRACT. The geological factors influencing the safe siting and construction of farm water storages in arid regions are discussed. An example of engineering geological mapping are discussed. An example of engineering geological mapping for the location of farm dams and tanks, from near Broken Hill, is described.

## INTRODUCTION

In the post-war impetus to civil engineering works in Australia, engineering geology finally established itself in this country as a necessary aspect of the design and construction of large structures. Before the 1939-45 war, with a few exceptions, lip service only had been paid for the most part by civil engineers to geology. With the hydroelectric development in Tasmania, Victoria, and the Snowy Mountains, and with other important works in Queensland, South Australia, and Western Australia, engineering geology came to take a major role in the safe and economic construction of dams, tunnels, underground power stations, pipelines, roads, airfields and bridges. Particularly in the twenty-year period from 1945 to 1965, Australian engineering geologists made a significant contribution to the development of this nation. Since 1965 the tempo of major development has slowed, and engineering geologists are tending to become more involved in environmental issues. Australia has a most enviable record in civil engineering works, with major engineering failures due to geological factors almost, if not totally, zero. The same is not true of one group of minor structures - farm dams. Here, the failure rate from various causes runs, in Australia, as high as 30% in some areas, and averages, throughout the country, over 25%. This is a field which obviously requires study and investigation; it was to this that my attention was turned about 1970, and it is an area in which and with which I have become vitally interested and concerned, following the pioneering work of C.S.I.R.O.

If a major dam fails, it is a national disaster. Property is destroyed and damaged, lives may be lost. If a farm dam fails - who cares? The farmer, of course, is affected. At present, even a modest dam on a farm costs upward of $10,000 to $40,000. If it fails, the farmer has suffered a very serious loss. If we extend this to 25% of the dams built on farms in Australia, the loss reaches serious economic proportions, not only in wasted capital expenditure, but in lost production. Despite my exploration colleagues' best efforts, Australia's economy is still highly dependent on farm production. The loss in production due to the high rate of dam failures on the farm can then be regarded as a very serious matter indeed.

* Presidential address delivered to the Royal Society of New South Wales at Science House, Gloucester Street, Sydney, on April 4, 1979.

The problem appears to be most serious in the arid and semi-arid regions where, of course, water is a more vlluable commodity than it is elsewhere. My own research has tended to be restricted to such regions, and, in this address, I am going to speak mainly of the problems in arid and semi-arid zones - which constitute a very large proportion of the Australian continent (Figure 1).


Fig. 1. Australia, showing 10-inch (250 mm) and 15-inch (375 mm) isohyets which define the boundaries of the arid and semi-arid zones.

## CAUSES OF FAILURE OF FARM WATER STORAGES

The failure of farm water storages is considered to be due to one or more of the following:

(a) Inadequate and/or unsuitable catchment area

(b) Excessive evaporation

(c) Excessive seepage

(d) Inadequate spillway provision

(e) Poor methods of construction in relation to the materials available, especially inadequate compaction

(f) Water quality unsatisfactory

(g) Structural failure due to piping as a result of the use of unsatisfactory materials.

Of these, the geologist is concerned with all but failure due to excessive evaporation. All of the other causes involve, to a greater or lesser degree, the soil and rock, their weathering, composition, structure, fabric and behaviour when processed. The weathering - both depth and degree, will influence the quantity and quality of runoff from a catchment, and the availability, and mechanical properties, of the soils used for construction. Structures in the rock-soil mass will control seepage losses. The fabric and composition of the soils will also influence seepage losses as well as bank stability and water quality. Knowledge of catchment geology combined with climatological and hydrological data will have a role in the provision of adequate spillways, while the geological control of landform may influence the location of the spillway.

TYPES OF FARM WATER STORAGES

Four main types of storage are used on farms in Australian arid and semi-arid regions (Figure 2):

(a) tank

(b) turkey's nest dam

(c) dam

(d) a combination of tank and dam.

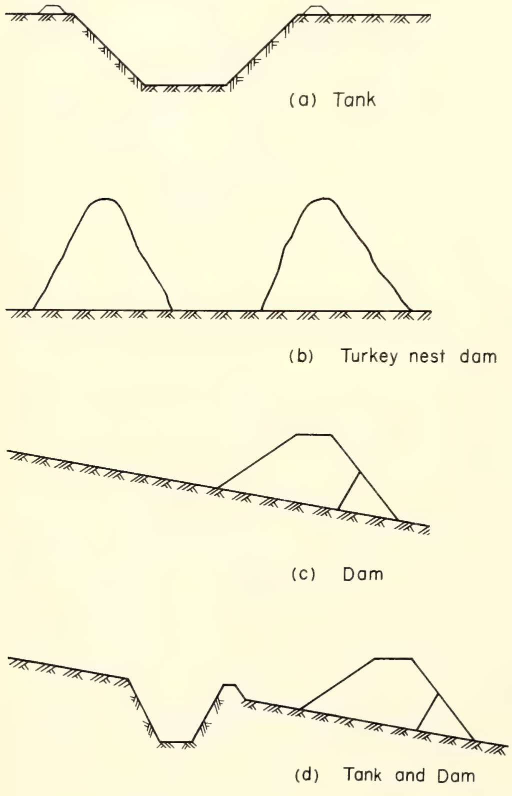



Fig. 2. Sections through typical farm water storages in dry regions.

The aim is to provide a storage with a low surface area - depth ratio to reduce the effects of evaporation. For this reason, the dam is not always the proper solution, since the surface area - depth ratio is almost always high. It is for this same reason that a tank, with its low surface area - depth ratio is often combined with a dam, and is located adjacent to the dam where the water will be deepest and, hence, evaporation losses less critical. The turkey's nest dam is used, in general, for the storage of pumped ground or surface water. It can be located anywhere provided soil is available - but of course it must be adjacent to the productive bore, or other source of pumped water.

GEOTECHNICAL ASPECTS OF SITE SELECTION AND DESIGN

The ultimate storage capacity of the tank or dam, the quantity and quality of water, and the development of soil erosion in the catchment and, hence, siltation of the storage will all be influenced by the surface conditions and soils of the catchment. Lewis (1964) cited the catchment requirement per 1 million gallons ($4.456 \times 10^6$ litres) storage as:

| | | |
|---|---|---|
| Grassed catchments | 100 acres | (40.5 ha) |
| Roaded catchments | 25 acres | (10 ha) |
| Rocky catchments | 10 acres | (4 ha) |

These estimates assume a minimum catchment gradient of 1:400. The catchment condition is important since insufficient yield can result in hydrological failure. In Australian arid regions, in any case, no substantial runoff occurs for rainfall events of less than 0.5 inch (12 mm), even under the best geological conditions.

The excavated tank is constructed using a bulldozer; the excavated material is either pushed aside, or used for the construction of banks, or of the nearby dam if this is proposed. The tank is located in, or close to, a stream channel, so that, if the catchment erodes, a silt trap will be required to minimise siltation of the tank. The tank must be located in soil or highly weathered rock to permit cheap excavation. Stable and impervious walls and floor are essential. Soils with a clay content of less than 10% are not satisfactory because of high permeability; however, since the clay content of many soils in arid regions tends to increase with depth, the lower level soils can be used to seal the higher levels of the tank wall. Salinity also tends to increase with depth (Stace, 1969); if this is the case, the transfer of low level soils to higher levels is undesirable, since it can increase the salinity of the higher level water.

Seepage through the floor and walls of a tank can be quite serious, and this is especially so if the soils contain expansive clays. Under such conditions (30% expansion/shrinkage has been recorded in desert soils: Beavis, Beavis and Reade, 1978) cracking occurs when the tank empties, and on refilling, initial seepage losses are aggravated, and the stability of the walls may be reduced. The dam site requires a suitable topographic location, together with a suitable impervious foundation and suitable materials for construction. It is imperative that the mechanical properties of the soils be known so that adequate compaction can be achieved

(inadequate compaction is one of the major causes of structural failure), stable slopes designed, and filter zones incorporated or other remedial procedures adopted if the soil is likely to fail by piping.

WATER LOSSES FROM TANKS AND DAMS

Evaporation and seepage are the two most significant causes of water loss. In the case of tanks, seepage losses can exceed or equal losses due to evaporation, but proper construction and foundation treatment should ensure that the seepage through small earth dams is minimal. Ingles (1974) has shown that seepage losses from tanks are not always fully appreciated. He showed that, for a tank with a capacity of 6 x $10^6$ gallons (2.67 x $10^7$ litres) a breadth-depth ratio of 8 and a soil mass permeability of $10^{-7}$cm/sec; the seepage losses amount to 0.5 inch (12 mm) per day. Since it is not uncommon for arid soils to have a permeability of $10^{-6}$ cm/sec, seepage losses could amount to 5 inches (127 mm) per day. Good construction with a soil of adequate clay content can achieve a permeability of $10^{-8}$ cm/sec with seepage losses reduced to 0.05 inch (1.27 mm) per day. Seepage losses are greatest through the floor of a tank and beneath and around a dam. The tank floor and soil foundation of a dam should be compacted with special care, or, in the case of fissured rock, a well compacted clay blanket should be provided.

Flocculated red clayey desert soils high in lime and/or gypsum have a very high permeability, and tanks excavated in such soils have high seepage losses. Seepage is aggravated by solution of the soluble minerals, which results in an increase in voids.

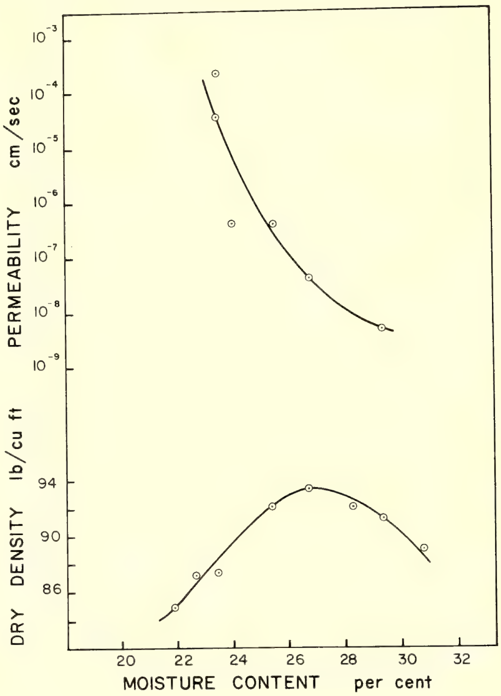



Fig. 3. Relationship between moisture content, density and permeability of a desert soil.

STRUCTURAL FAILURES OF FARM DAMS

If structural failure due to overtopping is excluded, structural failure of farm dams is due, in most cases either to inadequate compaction, and to piping. It is essential that a soil in a dam be compacted as closely as possible to maximum density. A clear relationship is known to exist between moisture content, density and permeability (Figure 3) and, if the best compaction is to be achieved, the soil must be placed, and compacted, at optimum moisture content. In Figure 4 it can be seen that some soils have flat moisture content-density curves, while curves for some other soils are much steeper. Those soils with the steep curves require careful treatment in placing and compaction, since even ± 1% moisture content can seriously affect the density achieved. In the event of poor compaction, failure of the embankment becomes a distinct possibility, while, of course, the higher the degree of compaction, the greater the density and the lower the permeability.

No matter how well compacted a soil may be, it is still permeable, and water will flow through it, and the foundation. If there is a concentration of seepage, with high hydraulic gradient, soil particles will be eroded from the downstream face of the dam, or from the foundation.

This erosion works its way upstream, parallel to flow lines, at an increasing speed, towards the source of the water. In this way a pipe is developed. Once the pipe breaks through to the storage, the opening is rapidly enlarged, water discharge increases, and structural failure follows almost immediately. Cohesionless soils such as sands and fine silts are particularly susceptible to piping. Clays resist piping since the interparticle bonds help to prevent the particles washing away. Most soils, as we know, are a mixture of various size grades ranging from clay to sand, and it is often difficult to assess the susceptibility of the soil to piping. Considerable research has gone into developing tests, which, for the purposes of farm dams, must be simple.

Figure 5 shows a chart based on experience and on laboratory testing. Although this chart is usefull, I, and my co-workers have found it to be as unreliable as the simple rule of thumb which says the plastic limit of a soil is ± 1% optimum moisture content. We have found plastic limits of -16% optimum in thixotropic desert soils, and soils which Figure 5 suggests are safe from piping to be extraordinarily susceptible to piping!

What is necessary from the researcher is the establishment of simple, reliable tests for susceptibility to piping, and for optimum moisture content, and to make the farmer aware of the limitations of these tests. It is also important to develop simple tests for compaction using e.g. penetrometers so that the farmer can assure himself

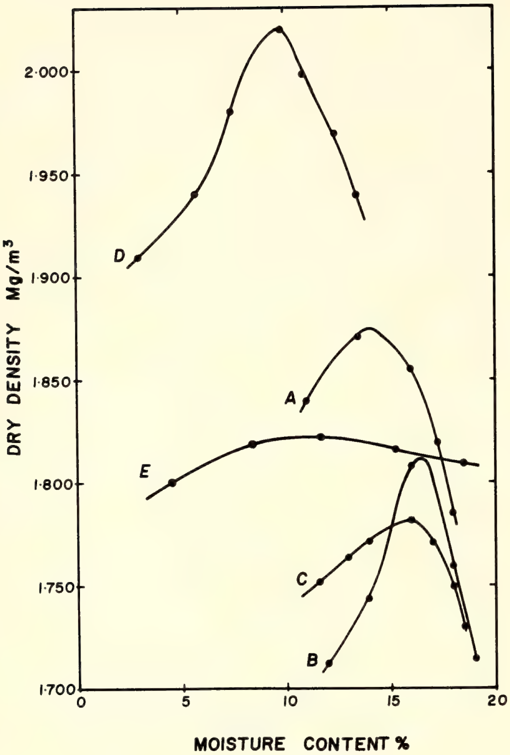



Fig. 4. Moisture content-density relations for five desert soils, near Broken Hill.

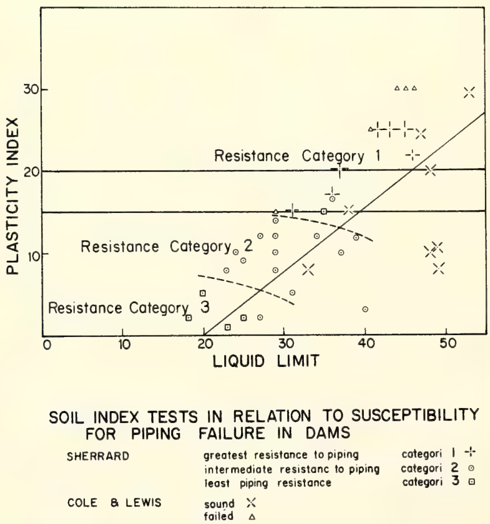



Fig. 5. Relationship between index properties of soils and susceptibility to piping.

that his dam is being properly constructed. Too often, moreover, the farmer builds his dam of the one material. The incorporation of a downstream filter zone will certainly reduce, if not eliminate, the possibility of failure by piping; the cost of transporting and placing the filter sand is negligible compared to the cost of failure.

SALINITY OF SOIL AND WATER

Sodium chloride in solution has a stabilizing effect on the soil. However, when saline soils are used in dam embankments, and if the water is non-saline, the dam stability is reduced and failure by piping becomes a highly probable event.

Even if the water has a very low salinity, storage tends to increase the salinity. Beavis, Beavis and Reade (1978) reported, from an area north of Broken Hill, the following data:

CATION CONCENTRATIONS

| ppm | $Na^+$ | $K^+$ | $Ca^{++}$ | $Mg^{++}$ |
|---|---|---|---|---|
| Stream | 13.0 | 7.0 | 15.0 | 0.3 |
| Storage | 33.0 | 4.1 | 31.2 | 0.2 |

ANION CONCENTRATIONS

| ppm | $HCO_3^-$ | $CO_3^=$ | $Cl^-$ | $SO_4^=$ | $NO_3^-$ |
|---|---|---|---|---|---|
| Stream | 68.4 | - | 25.6 | 4.0 | 0.42 |
| Storage | 122.04 | 4.8 | 26.6 | 7.0 | 0.13 |

which shows a certain degree of concentration, particularly of some ions, in the stored water, although it is apparent that some ions have a lower concentration under storage conditions. Have they been adsorbed onto clays?

With its greater density, saline water tends to accumulate in the lower levels of a deep storage. This low level saline water may not, therefore, be available for use since the salinity may exceed the tolerance of both animals and humans.

Saline water tends to promote flocculation of the soil and hence to increase permeability, and therefore, seepage losses. It has the beneficial effects of inhibiting the dispersion of the soil clays into the water, thus reducing the chance of bank failure. In excavated tanks, saline water seems to protect the walls against sliding.

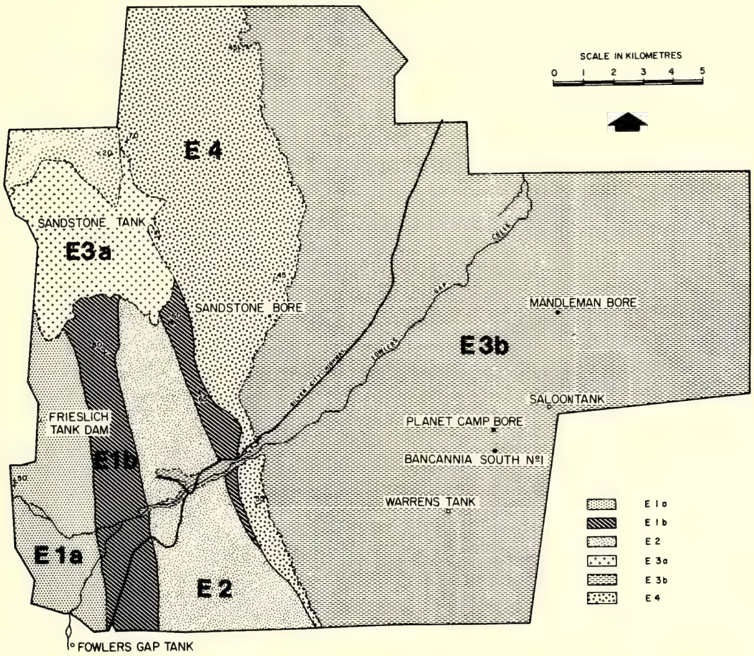
GEOTECHNICAL INVESTIGATIONS

Having outlined some of the principles involved, it is necessary now to consider the investigation work required of the geologist so that adequate data may be available for safe and economic construction. The mott important criteria are:

(a) the depth to which excavation can be made using bulldozer and ripper;

(b) the nature of the materials and their properties;

(c) the geology of the catchment.




| Unit | |
|---|---|
| E1a | Pre-Cambrian shales, with some quartzite and dolomite. Rock CW to 15 metres. Cover of colluvium: saline; thixotropic. Volume expansion on wetting >30%. Not suitable for construction.<br>Shale soils with salt, lime, gypsum to 2 metres; 12% volume expansion to 3 m, 5% below 3 m. Bulldozer excavation to 12+ metres. Suitable for tanks. Shale soils OMC 16%, MD 1.782 Mg/m$^3$. Compact at OMC + 1%-2%. Permeability 6.5 x 10$^{-5}$ cm/sec. LL 29%-45%, PL 16%-27%. Soil liable to piping.<br>Rock mass closely jointed. Blanket CW rock in tanks. |
| E1b | Rock CW to 5 m only. Tank excavation below 5 m requires use of explosives. Otherwise as for E1a. |
| E2 | Pre-Cambrian interbedded shales, quartzites, marble and dolomite. Rock CW to 2+ metres. Cover of colluvium as for E1. Unsuitable for tank excavation. Rock highly jointed. Good topographic dam sites, but foundation treatment to reduce leakage necessary. Leakage losses from existing dam high. Inadequate quantities of soils for construction. Soils saline. Volume expansion 14-32%. Some soils thixotropic. OMC 14%, MD 1.920 Mg/m$^3$. Compact at OMC $\pm$ 1.5%. Permeability 6 x 10$^{-6}$ cm/sec. LL 36%, PL 19%. Soils liable to piping. |
| E3a | Unconsolidated Tertiary sediments. Red clayey silty sand up to 16 metres thick. Suitable for tank excavation, but soils relatively permeable. Soil thixotropic. Volume expansion 5% to 21%. OMC 14%, MD 2.190 Mg/m$^3$. Compact at OMC $\pm$ 2%. Permeability 2 x 10$^{-4}$ cm/sec. LL 32%, PL - not determinable due to thixotropy. LL value doubtful. |
| E3b | Unconsolidated Tertiary sediments up to 150 m thick. Highly variable. Suitable for tanks. Test each site. |
| E4 | Cretaceous and Devonian shales, sandstones and quartzites. Rock CW to 4 m maximum. Tank excavation requires use of explosives. Good topographic dam sites, but foundation treatment required to prevent excess leakage; soils thin and volumes readily available inadequate for dam construction. OMC 10.5%, MD 2.050 Mg/m$^3$. Compact at OMC $\pm$ 1.5%. Permeability 1 x 10$^{-4}$ cm/sec. LL, PL not determined. |

Fig. 6. Engineering geology (water storage feasibility) map of Fowler's Gap Arid Zone Research Station.

The initial stage of the investigation is the catchment survey which records rock types, rock outcrops, surface conditions; soil types; soil chemistry; and slopes. Runoff characteristics need to be assessed. At the sites, some drilling is desirable to determine the depth and degree of weathering, and to sample for testing. In subsurface investigation, particular attention must be given to:

(i) occurrence of zones of high permeability;

(ii) occurrence of highly impervious zones;

(iii) the position of the water table (if present at the depth studied);

(iv) bedrock level and the weathering profile;

(v) concentrations of salt, lime, gypsum.

Field permeability tests may be carried out. These can be quite sophisticated, but we have found quite rough tests to be adequate, e.g. the time taken for the water level to fall 1 metre in a borehole.

Samples taken should be tested in the laboratory for behaviour on wetting and drying (is the soil a collapsing type; highly swelling, or thixotropic?); clay mineralogy, including ion exchange capacity and sodium absorption ratio; permeability; density; compaction; consolidation; shear characteristics and Atterberg limits. Data from such tests permit safe and economic design and construction.

## THE SITUATION WITH THE FARMER

Now of course, you may rightly ask: "Is the farmer to engage an engineering geologist and a design engineer? Surely this is a grossly impractical academic dream?" My answer to the first question is "no" and to the second "yes". What we are aiming to achieve is the recognition, within a given region, of "types" for which clear specifications can be laid down, and which the farmer may follow, perhaps in consultation with an extension officer. We certainly do not envisage each farmer having a detailed site study made for each dam, but rather, having available a district geotechnical study.

Within the area shown in Figure 6, four main units exist; these are clearly defined on the map. For each unit, detailed studies have been carried out, and for each is specified the general geotechnical situation, and the conditions which should be followed in excavation and construction. Precautions which should be taken are clearly stated, and warning signs to be noted, and for which professional advice should be sought, are given. This has been established on a pilot scale, for an area of 160 square miles, north of Broken Hill. A dam-tank system has been constructed successfully. This is a very small area indeed, but one of varying geology: it is, on a small scale, what one could expect to achieve on a large scale. At the present time, specifications for farm storages have been written by State authorities, but these take no account of the specific geotechnical conditions in the site region. As a result, many problems arise both during construction and when the storage is in service - and the failure rate remains high.

## CONCLUSIONS

If the farmer, and, in the final analysis, the country's rural industry, is to avoid costly failures of water storages, especially in arid and semi-arid areas, considerable research will be necessary to establish simple criteria for the siting and construction of water storages. I personally see this to be as great, if not a greater, challenge as that facing the engineering geologist on a large dam project. It is a challenge which few recognize, not least those providers of research funds; it is one which I regard as of perhaps not vital, but nonetheless considerable, importance to our community. One small team of researchers cannot hope to cover adequately more than a small region. If we are on the verge of establishing generally applicable principles, it is important that these principles be tested and applied on a wider scale.

## ACKNOWLEDGEMENTS

The work completed to date has been a team effort. I gratefully acknowledge the assistance of my co-workers: my wife, Joan, and Lee Reade. Associate Professor F.C. Loughnan determined the mineralogy of the soils. Part of the research described here, and extensions of it, are supported by grants from A.R.G.C., and the Reserve Bank of Australia. The figures were drawn by Marianne Horvath, and the manuscript typed by Diane McCloskey.

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# Precise Observations of Minor Planets at Sydney Observatory during 1978

D. S. KING

ABSTRACT. Positions of 1 Ceres, 3 Juno, 4 Vesta, 39 Laetitia, 51 Nemausa, 532 Herculina and 704 Interamnia obtained with the 23 cm camera are given.

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1978 are given here. The methods of observation were described in the first paper (Robertson 1958). All the plates were taken with the 23 cm camera (scale 116" to the millimeter). Four exposures were taken on each plate, except those for 704 Interamnia for which there were two.

In Table 1 are given the means of the positions for all the exposures using all six reference stars at the mean of the exposure times. The result for the first pair of images was compared with the results for the last pair by adding the motion computed from the ephemeris for the plates with four exposures. The means of the differences were $0^{s}.007 \sec \delta$ in right ascension and 0".12 in declination.

No correction has been applied for aberration, light time or parallax, but the factors give the parallax correction when divided by the distance. The column headed "0-C" gives the differences between the measured positions (corrected for parallax) and the position computed from the ephemerides supplied by the Institute for Theoretical Astronomy in Leningrad. The ephemeris for 51 Nemausa was obtained from L. K. Kristensen (University of Aarhus, Denmark).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table 2 gives for each observation the positions of the reference stars and the six star dependences. The reference star positions were converted to standard coordinates for the calculation of six star dependences. The column headed "R.A." and "Dec." give the seconds of time and arc with the proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Stars" gives the Durchmusterung number taken from either the AGK3 or SAO catalogue. The first column gives a serial number which cross-references Table 1 and Table 2 and also the catalogue from which the reference stars were taken.

All plates were reduced by both the methods of dependences and by first order plate constants using the same six reference stars. The r.m.s. residuals of the reference stars averaged at 0".24 for AGK3 stars and 0".56 for SAO stars.

The plates were measured by Mrs. A. Brown, Mrs. J. Close, Miss D. Teale and Miss J. Westaway. The observers at the telescope were D. S. King (K), T. L. Morgan (M), W. H. Robertson (R) and K. P. Sims (S).

ACKNOWLEDGMENTS

I wish to thank T. L. Morgan for his assistance and Mrs. J. Close for doing the reductions.

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TABLE 1

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | |
|---|---|---|---|---|---|---|---|---|
| | 1 Ceres 1978 U.T. | | | | | | | |
| 1607 | May 08.76780 | 19 43 05.436 | -24 42 15.33 | -0.022 | -1.38 | +0.01 | +0.1 | M |
| 1608 | June 06.69324 | 19 41 02.790 | -26 45 27.34 | -0.002 | -1.07 | +0.03 | +1.1 | K |
| 1609 | June 13.68548 | 19 37 17.745 | -27 23 28.39 | +0.046 | -0.98 | +0.08 | 0.0 | S |
| 1610 | July 03.60321 | 19 21 13.749 | -29 12 03.67 | -0.011 | -0.69 | -0.02 | +0.6 | K |
| 1611 | July 10.58380 | 19 14 30.794 | -29 45 20.79 | +0.004 | -0.61 | +0.01 | +0.5 | R |
| 1612 | July 24.55059 | 19 01 25.939 | -30 37 15.27 | +0.054 | -0.49 | -0.05 | +2.3 | S |
| 1613 | July 31.51062 | 18 55 46.304 | -30 54 56.95 | -0.006 | -0.43 | +0.02 | +1.5 | M |
| 1614 | Aug. 09.47595 | 18 49 54.975 | -31 09 54.90 | -0.027 | -0.40 | +0.03 | +0.3 | K |

TABLE 1 (Cont.)

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | |
|---|---|---|---|---|---|---|---|---|
| | 1 Ceres (Cont.) 1978 U.T. | | | | | | | |
| 1615 | Aug. 21.45984 | 18 45 13.884 | -31 18 08.53 | +0.044 | -0.38 | -0.02 | +0.6 | S |
| 1616 | Sep. 15.38839 | 18 47 53.228 | -31 05 08.24 | +0.026 | -0.41 | -0.05 | +1.5 | S |
| | 3 Juno 1978 U.T. | | | | | | | |
| 1617 | June 06.72958 | 20 27 48.467 | -03 59 17.36 | +0.011 | -4.36 | +0.05 | -0.7 | K |
| 1618 | June 13.71447 | 20 26 27.292 | -03 45 11.68 | +0.026 | -4.39 | -0.02 | +0.4 | S |
| 1619 | July 03.64047 | 20 16 49.779 | -03 44 25.97 | -0.013 | -4.39 | -0.03 | +0.5 | K |
| 1620 | July 10.61592 | 20 11 43.014 | -03 59 53.03 | -0.019 | -4.36 | -0.03 | +0.5 | R |
| 1621 | July 24.58282 | 19 59 55.669 | -04 55 29.84 | +0.022 | -4.24 | -0.05 | +0.3 | S |
| 1622 | Aug. 21.48917 | 19 38 19.216 | -07.57 16.62 | +0.015 | -3.82 | -0.04 | +0.4 | S |
| 1623 | Sep. 15.41503 | 19 31 59.659 | -10 53 13.70 | +0.011 | -3.41 | -0.03 | +1.0 | S |
| | 4 Vesta 1978 U.T. | | | | | | | |
| 1624 | Apr. 10.74711 | 17 15 43.677 | -15 13 20.17 | -0.005 | -2.78 | -0.02 | +0.2 | K |
| 1625 | Apr. 18.72449 | 17 18 09.946 | -15 10 34.50 | -0.013 | -2.78 | +0.02 | 0.0 | R |
| 1626 | May 01.70286 | 17 17 36.815 | -15 08 21.01 | +0.032 | -2.79 | +0.03 | +0.3 | S |
| 1627 | June 06.57919 | 16 50 38.130 | -15 47 31.65 | +0.011 | -2.69 | +0.05 | -0.3 | K |
| 1628 | June 13.56258 | 16 43 35.167 | -16 05 36.55 | +0.035 | -2.65 | +0.01 | 0.0 | S |
| 1629 | July 03.48696 | 16 27 55.184 | -17 16 02.45 | +0.002 | -2.47 | +0.04 | -0.3 | K |
| 1630 | July 10.47725 | 16 25 01.173 | -17 46 40.87 | +0.039 | -2.40 | -0.02 | -0.8 | S |
| 1631 | July 20.44623 | 16 23 43.982 | -18 34 38.22 | +0.030 | -2.28 | +0.03 | -0.1 | R |
| 1632 | July 25.43482 | 16 24 20.594 | -19 00 06.46 | +0.036 | -2.22 | -0.06 | +0.3 | M |
| 1633 | July 31.40312 | 16 26 08.554 | -19 31 29.60 | -0.018 | -2.14 | -0.01 | +0.4 | K |
| 1634 | Aug. 09.38291 | 16 30 56.180 | -20 19 47.01 | -0.014 | -2.02 | -0.02 | +0.8 | M |
| 1635 | Aug. 21.38035 | 16 40 53.157 | -21 24 13.17 | +0.062 | -1.88 | -0.03 | -0.7 | S |
| | 39 Laetitia 1978 U.T. | | | | | | | |
| 1636 | Aug. 14.76439 | 02 03 45.803 | +05 12 14.84 | -0.018 | -5.53 | +0.02 | -0.7 | R |
| 1637 | Sep. 05.70922 | 02 11 54.724 | +03 34 55.82 | -0.020 | -5.34 | +0.02 | -0.2 | M |
| 1638 | Sep. 12.71052 | 02 11 53.804 | +02 47 38.13 | +0.043 | -5.24 | +0.02 | -0.4 | K |
| 1639 | Sep. 27.64810 | 02 07 35.082 | +00 47 31.22 | -0.014 | -4.99 | +0.03 | -0.2 | R |
| 1640 | Oct. 09.61329 | 02 00 31.170 | -00 56 37.57 | -0.005 | -4.77 | +0.01 | -0.5 | K |
| 1641 | Oct. 23.56627 | 01 50 05.571 | -02 46 31.28 | -0.010 | -4.53 | +0.01 | -0.1 | R |
| 1642 | Nov. 21.48788 | 01 32 22.074 | -04 34 53.07 | +0.030 | -4.29 | 0.00 | -0.4 | S |
| 1643 | Dec. 05.43218 | 01 29 57.498 | -04 16 33.44 | -0.019 | -4.33 | -0.03 | -0.9 | R |
| | 51 Nemausa 1978 U.T. | | | | | | | |
| 1644 | Feb. 16.64447 | 10 55 40.367 | +00 44 22.26 | +0.044 | -4.95 | -0.01 | -0.5 | S |
| | 532 Herculina 1978 U.T. | | | | | | | |
| 1645 | Apr. 10.70366 | 15 40 31.614 | +05 54 39.13 | +0.065 | -5.58 | +0.03 | -0.5 | K |
| 1646 | Apr. 18.67243 | 15 36 15.307 | +06 29 40.04 | +0.045 | -5.65 | +0.03 | -0.5 | R |
| 1647 | May 01.61980 | 15 26 24.999 | +07 02 35.78 | +0.013 | -5.72 | +0.02 | -0.5 | S |
| 1648 | June 07.50962 | 14 56 52.334 | +04 45 48.38 | +0.048 | -5.45 | +0.02 | 0.0 | K |
| 1649 | June 23.43894 | 14 51 44.146 | +02 16 34.01 | -0.024 | -5.15 | +0.02 | +0.1 | K |
| 1650 | July 03.42120 | 14 51 50.500 | +00 28 25.94 | +0.005 | -4.92 | +0.02 | -0.1 | S |
| 1651 | July 10.41661 | 14 53 23.911 | -00 51 08.62 | +0.046 | -4.75 | +0.01 | -0.6 | K |
| 1652 | July 21.39234 | 14 58 07.000 | -02 58 56.12 | +0.054 | -4.47 | +0.05 | -0.6 | S |
| 1653 | July 31.36259 | 15 04 33.026 | -04 55 25.83 | +0.033 | -4.21 | 0.00 | +0.2 | K |
| | 704 Interamnia 1978 U.T. | | | | | | | |
| 1654 | June 08.50011 | 14 45 11.588 | -33 19 40.27 | +0.061 | -0.06 | -0.06 | +0.1 | K |
| 1655 | July 04.41633 | 14 37 53.218 | -30 08 10.88 | +0.032 | -0.53 | -0.04 | +0.9 | R |

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | Depend. | R.A. | Dec. | No. | Stars | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1607 | -25 14264 | 0.172817 | 16.950 | 50.04 | 1618 | - 4 5124 | 0.178652 | 24.702 | 44.57 |
| SAO | -24 15531 | 0.189586 | 35.498 | 12.36 | SAO | - 3 4900 | 0.173620 | 28.331 | 05.32 |
| | -25 14320 | 0.148756 | 54.984 | 04.90 | | - 4 5147 | 0.169821 | 59.178 | 40.41 |
| | -23 15724 | 0.191851 | 15.552 | 02.68 | | - 4 5156 | 0.163331 | 39.581 | 48.33 |
| | -23 15782 | 0.168490 | 23.810 | 13.54 | | - 3 4928 | 0.158253 | 30.229 | 44.00 |
| | -25 14375 | 0.128499 | 37.710 | 58.97 | | - 3 4930 | 0.156322 | 18.527 | 41.93 |
| 1608 | -27 14177 | 0.107237 | 54.088 | 06.63 | 1619 | - 3 4838 | 0.175514 | 12.984 | 46.56 |
| SAO | -26 14421 | 0.223791 | 38.589 | 06.42 | SAO | - 3 4840 | 0.160533 | 38.885 | 09.00 |
| | -27 14230 | 0.086619 | 16.759 | 43.17 | | - 4 5087 | 0.198848 | 21.160 | 55.63 |
| | -26 14460 | 0.260804 | 28.864 | 18.61 | | - 3 4848 | 0.150217 | 48.708 | 23.37 |
| | -27 14254 | 0.121169 | 14.522 | 18.13 | | - 3 4860 | 0.152698 | 51.233 | 52.70 |
| | -26 14504 | 0.200379 | 56.712 | 50.19 | | - 4 5110 | 0.162190 | 30.809 | 23.88 |
| 1609 | -27 14128 | 0.240744 | 51.754 | 47.94 | 1620 | - 4 5042 | 0.178151 | 26.824 | 23.70 |
| SAO | -27 14144 | 0.192810 | 52.361 | 38.68 | SAO | - 4 5043 | 0.137903 | 32.073 | 39.19 |
| | -27 14190 | 0.205466 | 43.251 | 45.16 | | - 3 4818 | 0.193433 | 36.117 | 58.62 |
| | -26 14421 | 0.107288 | 38.589 | 06.42 | | - 5 5189 | 0.129509 | 00.589 | 35.93 |
| | -27 14230 | 0.157877 | 16.759 | 43.17 | | - 3 4840 | 0.202512 | 38.885 | 09.00 |
| | -27 14239 | 0.095815 | 48.248 | 34.02 | | - 4 5087 | 0.158492 | 21.160 | 55.63 |
| 1610 | -29 16056 | 0.187505 | 38.562 | 08.70 | 1621 | - 5 5124 | 0.091148 | 17.781 | 16.81 |
| SAO | -29 16059 | 0.196694 | 48.027 | 40.50 | SAO | - 4 4984 | 0.122514 | 51.235 | 31.74 |
| | -28 15753 | 0.186605 | 50.539 | 05.50 | | - 4 4998 | 0.188866 | 56.724 | 45.50 |
| | -29 16104 | 0.154362 | 55.224 | 28.97 | | - 5 5140 | 0.163386 | 05.304 | 00.99 |
| | -28 15797 | 0.156061 | 37.229 | 51.53 | | - 4 5007 | 0.212376 | 22.591 | 33.41 |
| | -29 16144 | 0.118772 | 58.326 | 28.34 | | - 5 5156 | 0.221709 | 25.106 | 16.47 |
| 1611 | -30 16800 | 0.164564 | 26.225 | 06.13 | 1622 | - 8 5050 | 0.259793 | 29.954 | 10.78 |
| SAO | -29 15872 | 0.187980 | 30.441 | 48.73 | SAO | - 7 5024 | 0.157517 | 59.216 | 27.43 |
| | -30 16826 | 0.142527 | 55.331 | 09.76 | | - 8 5073 | 0.207233 | 54.348 | 48.03 |
| | -29 15977 | 0.194050 | 17.050 | 49.83 | | - 7 5042 | 0.109558 | 22.126 | 38.28 |
| | -30 16903 | 0.136088 | 45.182 | 40.17 | | - 7 5047 | 0.117097 | 30.582 | 43.96 |
| | -29 16021 | 0.174790 | 13.440 | 04.21 | | - 8 5085 | 0.148802 | 34.271 | 49.02 |
| 1612 | -31 16267 | 0.190084 | 10.454 | 38.41 | 1623 | -10 5097 | 0.100857 | 37.801 | 30.52 |
| SAO | -30 16580 | 0.172707 | 44.783 | 09.64 | SAO | -11 5030 | 0.160546 | 20.171 | 56.02 |
| | -30 16595 | 0.158096 | 38.571 | 17.52 | | -10 5111 | 0.127010 | 44.835 | 58.47 |
| | -31 16312 | 0.177065 | 32.829 | 24.86 | | -11 5044 | 0.195018 | 38.649 | 06.52 |
| | -30 16665 | 0.144104 | 02.519 | 18.15 | | -10 5131 | 0.182423 | 05.974 | 12.82 |
| | -30 16671 | 0.157944 | 16.197 | 50.50 | | -11 5062 | 0.234146 | 01.433 | 50.91 |
| 1613 | -30 16396 | 0.159917 | 16.104 | 46.71 | 1624 | -15 4502 | 0.277516 | 24.274 | 09.76 |
| SAO | -29 15525 | 0.177528 | 12.497 | 25.81 | SAO | -14 4598 | 0.185862 | 22.207 | 46.60 |
| | -31 16152 | 0.149297 | 13.271 | 16.89 | | -15 4511 | 0.248504 | 25.618 | 46.00 |
| | -32 14762 | 0.153287 | 16.127 | 44.80 | | -14 4615 | 0.061914 | 53.678 | 46.08 |
| | -31 16267 | 0.175029 | 10.454 | 38.41 | | -15 4521 | 0.145384 | 20.699 | 34.93 |
| | -30 16580 | 0.184942 | 44.783 | 09.64 | | -14 4619 | 0.080819 | 05.128 | 16.27 |
| 1614 | -30 16310 | 0.248104 | 46.583 | 20.82 | 1625 | -14 4585 | 0.190213 | 29.509 | 41.99 |
| SAO | -31 16066 | 0.209117 | 34.869 | 25.65 | SAO | -15 4502 | 0.156457 | 24.274 | 09.76 |
| | -31 16075 | 0.169708 | 23.495 | 08.80 | | -15 4511 | 0.129509 | 25.618 | 46.00 |
| | -30 16396 | 0.175407 | 16.104 | 46.71 | | -14 4619 | 0.182185 | 05.128 | 16.27 |
| | -31 16152 | 0.083019 | 13.271 | 16.89 | | -14 4644 | 0.190934 | 53.451 | 12.09 |
| | -31 16155 | 0.114644 | 17.940 | 39.73 | | -15 4554 | 0.150703 | 17.300 | 42.42 |
| 1615 | -31 15913 | 0.209122 | 23.944 | 07.90 | 1626 | -14 4585 | 0.308619 | 29.509 | 41.99 |
| SAO | -30 16169 | 0.139552 | 52.952 | 33.89 | SAO | -15 4502 | 0.197485 | 24.274 | 09.76 |
| | -31 15973 | 0.215888 | 57.542 | 41.83 | | -15 4513 | 0.061025 | 46.557 | 40.06 |
| | -30 16264 | 0.118108 | 09.615 | 39.23 | | -15 4534 | 0.073417 | 43.509 | 32.92 |
| | -31 16071 | 0.134061 | 12.599 | 52.19 | | -14 4644 | 0.243822 | 53.451 | 12.09 |
| | -31 16075 | 0.183269 | 23.495 | 08.80 | | -15 4554 | 0.115631 | 17.300 | 42.42 |
| 1616 | -31 15951 | 0.130563 | 03.606 | 23.37 | 1627 | -15 4393 | 0.182771 | 23.776 | 24.25 |
| SAO | -30 16225 | 0.123295 | 58.693 | 46.92 | SAO | -16 4353 | 0.211450 | 29.478 | 10.95 |
| | -32 14530 | 0.175723 | 08.080 | 17.48 | | -14 4492 | 0.152585 | 13.968 | 11.67 |
| | -30 16323 | 0.147632 | 11.827 | 40.42 | | -16 4371 | 0.183262 | 08.606 | 40.34 |
| | -31 16108 | 0.228659 | 15.132 | 40.64 | | -14 4512 | 0.119047 | 30.684 | 36.94 |
| | -30 16396 | 0.194129 | 16.104 | 46.70 | | -15 4421 | 0.150886 | 31.073 | 23.67 |
| 1617 | - 4 5146 | 0.156711 | 50.065 | 10.84 | 1628 | -15 4365 | 0.074339 | 40.820 | 35.38 |
| SAO | - 3 4912 | 0.089496 | 16.331 | 46.16 | SAO | -16 4327 | 0.081740 | 41.363 | 18.34 |
| | - 4 5153 | 0.312215 | 03.047 | 01.61 | | -14 4476 | 0.148614 | 48.195 | 03.02 |
| | - 3 4923 | 0.036139 | 20.534 | 56.94 | | -17 4631 | 0.183498 | 40.151 | 17.80 |
| | - 4 5166 | 0.254564 | 23.682 | 30.03 | | -15 4393 | 0.249372 | 23.776 | 24.25 |
| | - 4 5168 | 0.150875 | 46.123 | 21.47 | | -16 4354 | 0.262437 | 35.133 | 01.65 |

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | Depend. | R.A. | Dec. | No. | Stars | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1629 | -17 4581 | 0.240491 | 51.435 | 05.02 | 1640 | - 1 271 | 0.193515 | 38.644 | 59.67 |
| SAO | -17 4580 | 0.174940 | 51.927 | 31.15 | AGK3 | - 1 272 | 0.215396 | 47.448 | 09.91 |
| | -17 4585 | 0.125758 | 45.618 | 53.88 | | - 2 345 | 0.151134 | 07.632 | 52.04 |
| | -16 4298 | 0.307654 | 16.274 | 20.24 | | - 0 310 | 0.189046 | 26.060 | 23.94 |
| | -17 4601 | 0.022189 | 57.982 | 03.42 | | - 1 291 | 0.109859 | 32.759 | 49.71 |
| | -16 4315 | 0.128969 | 07.399 | 35.32 | | - 0 320 | 0.141050 | 41.313 | 34.68 |
| 1630 | -18 4274 | 0.087700 | 13.591 | 26.14 | 1641 | - 3 260 | 0.154777 | 01.172 | 38.56 |
| SAO | -17 4563 | 0.281997 | 48.397 | 48.26 | SAO | - 2 298 | 0.136993 | 05.966 | 46.79 |
| | -18 4281 | 0.026716 | 45.644 | 12.59 | | - 4 287 | 0.184107 | 21.203 | 03.98 |
| | -17 4581 | 0.295135 | 51.435 | 05.02 | | - 2 312 | 0.154774 | 37.450 | 53.93 |
| | -18 4287 | 0.099719 | 48.565 | 15.12 | | - 3 281 | 0.187049 | 37.878 | 10.49 |
| | -17 4594 | 0.208733 | 29.811 | 51.33 | | - 2 328 | 0.182299 | 05.521 | 28.55 |
| 1631 | -18 4266 | 0.170091 | 35.233 | 17.61 | 1642 | - 4 218 | 0.122878 | 09.749 | 42.85 |
| SAO | -17 4563 | 0.195998 | 48.397 | 48.26 | SAO | - 5 271 | 0.164152 | 28.223 | 02.82 |
| | -19 4368 | 0.143430 | 31.021 | 25.56 | | - 3 216 | 0.111216 | 33.984 | 13.12 |
| | -17 4575 | 0.189213 | 07.164 | 04.28 | | - 5 282 | 0.208049 | 13.584 | 09.26 |
| | -18 4287 | 0.169817 | 48.565 | 15.13 | | - 4 247 | 0.161372 | 29.663 | 26.44 |
| | -20 4509 | 0.131451 | 58.526 | 18.80 | | - 5 296 | 0.232333 | 51.876 | 54.84 |
| 1632 | -18 4266 | 0.148922 | 35.233 | 17.61 | 1643 | - 4 220 | 0.243929 | 15.290 | 24.85 |
| SAO | -17 4563 | 0.127086 | 48.397 | 48.26 | SAO | - 5 271 | 0.228409 | 28.223 | 02.82 |
| | -19 4368 | 0.188969 | 31.021 | 25.56 | | - 3 216 | 0.187826 | 33.984 | 13.12 |
| | -17 4575 | 0.141216 | 07.164 | 04.28 | | - 4 237 | 0.127491 | 19.083 | 44.95 |
| | -18 4287 | 0.166742 | 48.565 | 15.13 | | - 5 285 | 0.121284 | 09.452 | 57.92 |
| | -20 4506 | 0.227065 | 28.921 | 47.61 | | - 5 287 | 0.091061 | 10.870 | 26.60 |
| 1633 | -19 4368 | 0.221705 | 31.021 | 25.56 | 1644 | + 1 2504 | 0.187940 | 26.159 | 31.88 |
| SAO | -18 4281 | 0.236008 | 45.644 | 12.59 | AGK3 | + 1 2507 | 0.126621 | 02.712 | 50.98 |
| | -21 4366 | 0.106328 | 21.662 | 34.95 | | + 1 2606 | 0.171738 | 13.502 | 49.09 |
| | -18 4287 | 0.218632 | 48.565 | 15.13 | | + 1 2503 | 0.222638 | 20.048 | 49.82 |
| | -20 4506 | 0.103195 | 28.921 | 47.61 | | + 0 2721 | 0.156006 | 52.182 | 13.72 |
| | -18 4297 | 0.114132 | 36.898 | 28.81 | | + 0 2722 | 0.135057 | 19.810 | 15.84 |
| 1634 | -19 4368 | 0.062561 | 31.021 | 25.56 | 1645 | + 6 3085 | 0.287394 | 20.573 | 20.45 |
| SAO | -21 4366 | 0.132694 | 21.662 | 34.95 | AGK3 | + 6 3087 | 0.235201 | 53.954 | 42.31 |
| | -18 4287 | 0.118416 | 48.565 | 15.14 | | + 5 3066 | 0.168714 | 05.730 | 19.01 |
| | -21 4389 | 0.225719 | 30.439 | 30.23 | | + 6 3089 | 0.154407 | 53.293 | 51.07 |
| | -18 4297 | 0.224929 | 36.898 | 28.81 | | + 5 3078 | 0.077474 | 22.434 | 05.66 |
| | -20 4526 | 0.235682 | 46.314 | 46.95 | | + 6 3096 | 0.076810 | 45.967 | 56.89 |
| 1635 | -20 4526 | 0.134987 | 46.314 | 46.95 | 1646 | + 7 2980 | 0.131632 | 39.565 | 14.61 |
| SAO | -21 4394 | 0.155381 | 01.328 | 45.77 | AGK3 | + 6 3066 | 0.217012 | 05.658 | 24.22 |
| | -20 4547 | 0.161475 | 40.186 | 12.60 | | + 7 2997 | 0.121501 | 10.824 | 06.06 |
| | -22 4199 | 0.178376 | 17.803 | 54.13 | | + 6 3083 | 0.174555 | 58.519 | 46.75 |
| | -20 4561 | 0.180289 | 14.640 | 37.80 | | + 6 3085 | 0.248808 | 20.573 | 20.45 |
| | -21 4420 | 0.189491 | 36.921 | 14.70 | | + 7 3007 | 0.106493 | 31.431 | 24.08 |
| 1636 | + 4 343 | 0.167182 | 12.813 | 09.60 | 1647 | + 7 2961 | 0.274434 | 46.149 | 00.61 |
| AGK3 | + 5 278 | 0.236442 | 44.169 | 54.97 | AGK3 | + 6 3048 | 0.087524 | 14.050 | 27.72 |
| | + 3 279 | 0.077504 | 23.980 | 17.04 | | + 7 2969 | 0.391429 | 18.105 | 37.34 |
| | + 5 285S | 0.233323 | 09.866 | 52.70 | | + 6 3053 | 0.019646 | 36.823 | 51.64 |
| | + 3 288 | 0.108440 | 03.644 | 48.48 | | + 6 3054 | 0.088083 | 23.140 | 51.46 |
| | + 4 362 | 0.177109 | 19.080 | 59.70 | | + 7 2975 | 0.138884 | 05.961 | 50.03 |
| 1637 | + 3 293 | 0.205151 | 16.873 | 31.27 | 1648 | + 4 2937 | 0.266675 | 53.659 | 47.65 |
| AGK3 | + 2 347 | 0.158012 | 40.356 | 40.43 | AGK3 | + 4 2943 | 0.086911 | 07.796 | 15.35 |
| | + 4 366 | 0.210531 | 38.887 | 59.25 | | + 5 2953 | 0.369183 | 41.048 | 38.35 |
| | + 1 406 | 0.119907 | 14.960 | 42.55 | | + 4 2945 | 0.037781 | 09.258 | 22.69 |
| | + 3 317 | 0.174669 | 36.346 | 21.05 | | + 4 2952 | 0.060368 | 17.373 | 54.63 |
| | + 2 358 | 0.131730 | 34.309 | 26.34 | | + 5 2962 | 0.179082 | 50.796 | 45.48 |
| 1638 | + 2 346 | 0.221050 | 07.519 | 05.60 | 1649 | + 2 2875 | 0.099263 | 50.909 | 02.76 |
| AGK3 | + 2 347 | 0.245697 | 40.356 | 40.43 | AGK3 | + 3 2948 | 0.176067 | 37.349 | 47.48 |
| | + 3 310 | 0.136555 | 31.630 | 10.12 | | + 2 2882 | 0.148152 | 14.590 | 41.68 |
| | + 1 398 | 0.206481 | 41.688 | 32.37 | | + 3 2955 | 0.207588 | 24.368 | 14.75 |
| | + 2 358 | 0.075099 | 34.309 | 26.34 | | + 2 2887 | 0.201166 | 54.468 | 07.92 |
| | + 1 412 | 0.115118 | 44.055 | 07.13 | | + 1 3001 | 0.167764 | 48.713 | 48.26 |
| 1639 | + 0 352 | 0.208568 | 13.715 | 15.41 | 1650 | + 0 3259 | 0.207667 | 57.055 | 59.48 |
| AGK3 | - 0 319 | 0.100848 | 32.125 | 53.86 | AGK3 | + 1 2992 | 0.207595 | 24.418 | 07.66 |
| | + 1 377 | 0.259443 | 06.725 | 12.86 | | + 0 3264 | 0.175914 | 12.632 | 17.74 |
| | - 0 327 | 0.083598 | 50.731 | 38.22 | | + 1 3002 | 0.157811 | 59.981 | 00.06 |
| | + 0 367 | 0.230184 | 39.983 | 20.71 | | + 0 3276 | 0.125347 | 08.158 | 37.63 |
| | - 0 335 | 0.117360 | 58.977 | 05.63 | | + 1 3005 | 0.125667 | 28.618 | 49.74 |

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | Depend. | R.A. | Dec. | No. | Stars | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1651 | - 0 2897 | 0.172873 | 14.405 | 34.26 | 1654 | -32 10330 | 0.135185 | 05.844 | 50.96 |
| AGK3 | + 0 3264 | 0.119279 | 12.632 | 17.74 | SAO | -33 10043 | 0.162709 | 14.219 | 03.36 |
| | - 0 2902 | 0.204196 | 01.131 | 53.62 | | -32 10347 | 0.134627 | 24.242 | 00.31 |
| | + 0 3276 | 0.104131 | 08.158 | 37.63 | | -32 10397 | 0.163627 | 07.162 | 39.15 |
| | - 0 2906 | 0.211762 | 49.629 | 49.93 | | -33 10113 | 0.209001 | 11.420 | 42.69 |
| | - 0 2910 | 0.187760 | 05.357 | 20.41 | | -33 10115 | 0.194851 | 28.003 | 42.83 |
| 1652 | - 3 3698 | 0.154378 | 06.113 | 53.43 | 1655 | -29 11212 | 0.227474 | 03.092 | 15.21 |
| SAO | - 2 3921 | 0.211582 | 06.733 | 00.48 | SAO | -30 11604 | 0.229468 | 57.845 | 23.60 |
| | - 1 3006 | 0.223036 | 26.698 | 05.70 | | -28 10870 | 0.116005 | 27.707 | 14.28 |
| | - 3 3707 | 0.119036 | 33.318 | 01.60 | | -29 11246 | 0.172843 | 51.136 | 00.52 |
| | - 2 3936 | 0.167720 | 26.344 | 39.63 | | -29 11252 | 0.117359 | 34.649 | 12.24 |
| | - 3 3717 | 0.124249 | 07.792 | 16.89 | | -29 11260 | 0.136851 | 09.850 | 48.57 |
| 1653 | - 3 3713 | 0.071605 | 02.345 | 06.99 | | | | | |
| SAO | - 5 3999 | 0.151799 | 53.689 | 17.02 | | | | | |
| | - 3 3726 | 0.112781 | 21.233 | 34.31 | | | | | |
| | - 5 4011 | 0.218031 | 18.325 | 26.52 | | | | | |
| | - 3 3735 | 0.194593 | 56.341 | 50.51 | | | | | |
| | - 4 3818 | 0.251190 | 56.575 | 17.79 | | | | | |

Sydney Observatory,
Sydney, N.S.W., 2000.

(Manuscript received 7-3-79)

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# Proper Motions in the Region of the Galactic Cluster N.G.C. 4103

D. S. King

ABSTRACT. Relative proper motions of stars in the region of the galactic cluster NGC 4103 based on plates taken with the 33cm astrograph, are determined with the aim of identifying stars which are non-members. The relative proper motions have an average standard error of 0".08/century and reveal 102 likely non-members and 69 likely members.

## INTRODUCTION

The open cluster NGC 4103 (R.A. = $12^h\ 01^m.5$, Dec. = $-60^\circ\ 41'$, 1900; $l$ = $297^\circ.6$, b = $+01^\circ.2$) has been studied photometrically by Wesselink (1969). The present investigation seeks to identify from their proper motions, those stars that are not members of the cluster.

## THE PLATES

The plates were taken with the 33cm standard astrograph (scale 1' = 1 mm) as follows:

| | Plate No. | Date Taken | Exposure | Plate Pair |
|---|---|---|---|---|
| 1 | 1326s | 1894 Mar. 25 | 5 m | 8 |
| 2 | 1326s | 1894 Mar. 25 | 2½ m | 7 |
| 3 | 2360s | 1895 Mar. 25 | 1 m | 6 |
| 4 | 2360s | 1895 Mar. 25 | ½ m | 5 |
| 5 | 2875s | 1896 Mar. 17 | 30 m | 1 |
| 6 | 3360s | 1897 May 3 | 30 m | 2 |
| 7 | 252RH | 1900 Mar. 9 | 3 m | 12 |
| 8 | 252RH | 1900 Mar. 9 | 1½ m | 11 |
| 9 | N1042 | 1924 Mar. 31 | 4 m | 4 |
| 10 | N1042 | 1924 Mar. 31 | 2 m | 3 |
| 11 | N1178 | 1925 Mar. 17 | 4 m | 10 |
| 12 | N1178 | 1925 Mar. 17 | 2 m | 9 |
| 13 | 7717Sa | 1978 Mar. 14 | 9½ m | 5 |
| 14 | 7727Sa | 1978 Apr. 18 | 12 m | 7 |
| 15 | 7728Sa | 1978 Apr. 18 | 12 m | 6 |
| 16 | 7732Sa | 1978 Apr. 27 | 18 m | 8 |
| 17 | 7733Sa | 1978 Apr. 27 | 16 m | 9 |
| 18 | 7734Sa | 1978 Apr. 27 | 10 m | 11 |
| 19 | 7735Sa | 1978 Apr. 27 | 20 m | 4 |
| 20 | 7736Sa | 1978 May 1 | 20 m | 1 |
| 21 | 7737Sa | 1978 May 1 | 20 m | 2 |
| 22 | 7742Sa | 1978 May 24 | 20 m | 10 |
| 23 | 7743Sa | 1978 May 24 | 20 m | 12 |
| 24 | 7744Sa | 1978 May 24 | 18 m | 3 |

Plate pairs 1-6 were centred at R.A. $12^h08^m$ Dec. $-61^\circ00'$ (1900). Plate pairs 7-12 were centred at R.A. $12^h00^m$ Dec. $-60^\circ00'$ (1900).

## MEASUREMENT

The plates were each measured in a Grubb-Parsons photoelectric measuring machine in both direct and reverse positions. The reverse positions were converted into direct measures using plate constants and the average was recorded. All stars measured were selected from the published coordinates in the Astrographic Catalogue (Sydney Observatory 1954, plate N1042). The plates were measured by Mrs J. Close, Miss D. Teale, Miss J. Westaway and Mr. D. King.

## REDUCTIONS AND PROBABILITIES

If $X_1$, $X_2$ are the measures of x on the new and old plates, $\mu$ is the annual proper motion and t is the time interval between the plates, then we can write:- $X_1 - X_2 = \mu t + ax + by + c + dm$ with a similar expression for $Y_1 - Y_2$ where x, y are taken from the new plate measures and m (magnitude) is taken from the Astrographic Catalogue. A least squares solution without the proper motion term was then calculated using all the stars measured on that plate pair. The solution was performed with a Diehl Alphatronic programmable calculator. Those stars whose residuals exceed 25 microns are eliminated from the solution and a further least squares solution sought of the remaining stars. This was repeated for successive limiting residuals of 10, 7.5 and 5 microns. The final standard deviation of the stars in the solution is usually approximately 2 microns i.e. 0".12. The resultant proper motion plate constants were then used to give the proper motions relative to the mean motion of the cluster. This is converted to a centennial proper motion by multiplying by 100k/t where k is the scale factor to convert measured differences to seconds of arc (k = 0".059735/micron).

A weight was assigned to each of the 12 plate pairs by averaging the proper motion for each star and taking the difference between the individual motions and the average as a residual for that plate pair. Then the variance of these residuals over all the stars measured on that plate pair gives weights both in x and y for that plate pair. The method of Sanders (1971) is then used on the weighted averages to determine the distribution parameters of a bivariate gaussian frequency function which represents the calculated field and cluster star relative proper motions. The distribution parameters in arc sec./century after eliminating 15 stars with very large proper motions were:

$$\theta = -8^\circ.11 \quad N_f = 87 \quad X_f = -0.041 \quad \Sigma_x = 0.333$$
$$\sigma_c = 0.103 \quad N_c = 69 \quad Y_f = 0.028 \quad \Sigma_y = 0.225$$

$\theta$ is the rotation angle of the observed proper motions ($+\mu_x$ to $+\mu_y$) into a new coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions. All the other parameters are defined in this new coordinate system. $\sigma_c$ is the dispersion of the

cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars; $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions. These parameters were then used to obtain a star's probability of membership.

The standard errors for individual stars have been grouped by their magnitudes, and the mean of the standard errors $\sigma_x$, $\sigma_y$ determined for different ranges are as follows:-

| Magnitude | $\sigma_x$ | $\sigma_y$ | No. of stars |
|---|---|---|---|
| | (Unit 0".01/cent) | | |
| 11.5 - 11.8 | 8.72 | 9.04 | 74 |
| 11.0 - 11.4 | 7.23 | 7.20 | 44 |
| 10.0 - 10.9 | 6.50 | 6.38 | 24 |
| 9.0 - 9.9 | 5.94 | 5.63 | 16 |
| 7.5 - 8.9 | 6.08 | 5.46 | 13 |
| All | 7.56 | 7.60 | 171 |

There were not enough Cape Catalogue stars measured to give an accurate absolute proper motion.

The observational data follows in table 1. The various columns are:-

No. The number from the Astrographic Catalogue, Sydney Section ($12^h\ 08^m$ - $61^o$ centre).
Mag. The magnitude of the star as determined by the image diameter.
R.A. Right ascension (1950), all prefixed by 12 hours.
Dec. Declination (1950).
CPD No. Prefixed by - $60^o$.
V Photovisual magnitude from Wesselink.
W No. Wesselink number.
$\mu_x$,$\mu_y$ Centennial proper motion in units of 0".01/cent. The axes are parallel to R.A. and Dec.
$\sigma_x$,$\sigma_y$ Standard errors of centennial proper motion in units of 0".01/cent.
P Probability of membership.
Notes 1 - A1 Crucis, an eclipsing variable.
6 - Not used in calculation of distribution parameters.

ACKNOWLEDGMENTS

I wish to thank the staff of Sydney Observatory who helped with the measuring and typing.

REFERENCES

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TABLE 1

THE OBSERVATIONAL DATA

| No. | Mag. | R.A. | Dec. | CPD No. | V | W No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1082 | 10.8 | 05 57 | -61 10 45 | 3782 | | | 6 | 11 | 7 | 7 | 75 | |
| 1083 | 11.8 | 05 45 | -61 09 05 | | | | -29 | 2 | 4 | 13 | 12 | |
| 1084 | 11.8 | 05 41 | -61 10 53 | | | | 292 | -70 | 3 | 8 | 0 | 6 |
| 1085 | 11.8 | 05 33 | -61 10 26 | | | | -51 | 1 | 12 | 8 | 0 | |
| 1086 | 11.6 | 05 31 | -61 08 24 | | | | 5 | -31 | 6 | 8 | 15 | |
| 1087 | 11.3 | 05 23 | -61 09 37 | | | | 3 | - 2 | 8 | 7 | 85 | |
| 1088 | 11.8 | 05 14 | -61 08 31 | | | | 43 | -16 | 11 | 14 | 0 | |
| 1089 | 11.8 | 05 00 | -61 08 10 | | | | 23 | 25 | 12 | 14 | 5 | |
| 1090 | 11.6 | 04 53 | -61 08 37 | | | | 20 | 1 | 8 | 9 | 53 | |
| 1091 | 11.2 | 04 53 | -61 07 10 | | | | -26 | -13 | 6 | 6 | 13 | |
| 1092 | 9.5 | 04 45 | -61 07 42 | 3760 | | | 14 | 3 | 6 | 5 | 72 | |
| 1093 | 11.3 | 04 34 | -61 06 20 | | | | -99 | -35 | 7 | 7 | 0 | |
| 1094 | 11.4 | 04 27 | -61 06 57 | | | | 9 | - 3 | 9 | 10 | 81 | |
| 1095 | 11.6 | 04 18 | -61 07 20 | | | | -26 | 27 | 6 | 11 | 2 | |
| 1096 | 11.8 | 04 17 | -61 10 01 | | | | 59 | 5 | 10 | 9 | 0 | |
| 1098 | 9.5 | 03 57 | -61 09 49 | 3734 | | | 6 | 0 | 5 | 4 | 84 | |
| 1099 | 11.7 | 03 38 | -61 09 57 | | | | 22 | 11 | 7 | 9 | 32 | |
| 1100 | 11.8 | 03 08 | -61 09 06 | | | | -28 | 39 | 11 | 13 | 0 | |
| 1101 | 11.5 | 02 58 | -61 08 34 | | | | -323 | 43 | 6 | 9 | 0 | 6 |
| 1102 | 11.4 | 02 58 | -61 08 16 | | | | -45 | 7 | 8 | 8 | 0 | |
| 1104 | 11.2 | 02 50 | -61 07 18 | | | | -32 | 20 | 6 | 7 | 1 | |
| 1105 | 11.7 | 02 32 | -61 08 34 | | | | 73 | 12 | 11 | 10 | 0 | |
| 1106 | 11.4 | 02 27 | -61 05 44 | | | | 10 | -12 | 7 | 6 | 71 | |
| 1107 | 9.2 | 02 24 | -61 06 29 | 3700 | | | - 3 | - 9 | 6 | 4 | 81 | |
| 1108 | 10.4 | 02 22 | -61 05 44 | 3698 | | | -58 | -10 | 7 | 7 | 0 | |
| 1187 | 11.5 | 05 19 | -61 01 13 | | | | -24 | 9 | 7 | 4 | 24 | |
| 1188 | 10.8 | 05 12 | -61 05 21 | 3765 | | | -53 | - 9 | 7 | 5 | 0 | |
| 1190 | 11.8 | 05 01 | -61 04 57 | | | | - 5 | 8 | 10 | 10 | 79 | |
| 1191 | 11.8 | 04 47 | -61 03 28 | | | | 12 | -41 | 10 | 10 | 1 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | W No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1192 | 11.2 | 04 25 | -61 03 14 | 3751 | | | - 2 | 6 | 6 | 5 | 83 | |
| 1193 | 11.8 | 04 23 | -61 04 10 | | | | 82 | 0 | 10 | 6 | 0 | |
| 1194 | 11.8 | 04 16 | -61 05 13 | | | | -42 | 7 | 2 | 10 | 0 | |
| 1195 | 11.7 | 04 00 | -61 04 45 | | | | 3 | 40 | 3 | 10 | 1 | |
| 1197 | 11.4 | 03 54 | -61 01 01 | | 12.22 | 53 | 16 | -19 | 7 | 8 | 38 | |
| 1200 | 10.8 | 03 29 | -61 03 37 | 3721 | | | 12 | 4 | 4 | 7 | 75 | |
| 1201 | 11.2 | 03 08 | -61 05 40 | | | | - 8 | 4 | 8 | 7 | 80 | |
| 1202 | 11.6 | 02 59 | -61 04 25 | | | | -15 | 12 | 11 | 5 | 54 | |
| 1204 | 8.6 | 02 51 | -61 03 56 | 3712 | | | -93 | 83 | 6 | 5 | 0 | 6 |
| 1205 | 11.2 | 02 49 | -61 01 11 | | | | -189 | -35 | 7 | 6 | 0 | 6 |
| 1206 | 10.0 | 02 46 | -61 03 22 | 3709 | | | 14 | - 5 | 5 | 6 | 71 | |
| 1207 | 11.2 | 02 44 | -61 02 21 | 3708 | | | 0 | - 9 | 7 | 9 | 82 | |
| 1208 | 11.7 | 02 42 | -61 02 07 | | | | -10 | 52 | 8 | 13 | 0 | |
| 1209 | 8.7 | 02 38 | -61 01 28 | 3707 | | | 2 | - 3 | 5 | 4 | 85 | |
| 1210 | 11.8 | 02 34 | -61 04 56 | | | | -13 | -22 | 12 | 7 | 31 | |
| 1211 | 11.8 | 02 29 | -61 03 41 | | | | 13 | 54 | 2 | 12 | 0 | |
| 1294 | 9.0 | 05 51 | -60 58 20 | 3780 | | | -17 | 23 | 6 | 6 | 17 | |
| 1295 | 10.0 | 05 30 | -61 01 03 | 3770 | | | -20 | -10 | 5 | 5 | 40 | |
| 1296 | 10.8 | 05 24 | -60 58 13 | 3768 | | | -10 | 1 | 4 | 4 | 78 | |
| 1297 | 11.7 | 05 08 | -61 00 50 | | | | 28 | -16 | 7 | 4 | 9 | |
| 1298 | 11.8 | 05 06 | -61 01 00 | | | | 11 | 27 | 9 | 8 | 16 | |
| 1299 | 11.2 | 05 06 | -60 59 11 | | | | 10 | 2 | 5 | 7 | 79 | |
| 1300 | 11.7 | 05 01 | -61 00 41 | | | | 13 | -35 | 11 | 10 | 4 | |
| 1302 | 11.2 | 04 39 | -60 56 16 | 3759 | | | 0 | - 1 | 6 | 8 | 85 | |
| 1303 | 11.6 | 04 37 | -60 59 48 | | | | 9 | -13 | 6 | 9 | 71 | |
| 1304 | 8.9 | 04 35 | -60 59 09 | 3757 | 9.06 | 10 | 5 | - 9 | 6 | 5 | 80 | |
| 1305 | 10.7 | 04 27 | -60 56 56 | 3754 | 10.99 | 9 | 8 | 5 | 7 | 7 | 80 | |
| 1306 | 9.8 | 04 24 | -61 00 55 | 3749 | 10.01 | 14 | 7 | - 3 | 6 | 6 | 83 | |
| 1307 | 8.4 | 04 21 | -60 59 21 | 3748 | 9.43 | 11 | 5 | 3 | 5 | 5 | 83 | |
| 1308 | 11.8 | 04 19 | -60 57 34 | | 12.61 | 49 | 17 | 15 | 11 | 6 | 41 | |
| 1309 | 11.8 | 04 18 | -61 00 47 | | 12.92 | 73 | -17 | 31 | 7 | 7 | 4 | |
| 1310 | 11.2 | 04 17 | -60 58 59 | | 11.88 | 47 | 10 | 2 | 8 | 7 | 79 | |
| 1311 | 7.7 | 04 16 | -60 59 32 | 3746 | 9.20 | 12 | - 3 | 2 | 5 | 4 | 84 | |
| 1312 | 11.2 | 04 16 | -60 57 13 | | 12.01 | 50 | 6 | -13 | 7 | 6 | 74 | |
| 1315 | 11.8 | 04 15 | -60 57 54 | | 13.12 | 254 | 15 | -31 | 8 | 14 | 7 | |
| 1316 | 11.8 | 04 14 | -60 57 03 | | 13.10 | 299 | -14 | 47 | 4 | 11 | 0 | |
| 1317 | 11.2 | 04 12 | -60 57 38 | | 11.6 | 251 | - 3 | -22 | 6 | 6 | 50 | |
| 1318 | 9.8 | 04 11 | -60 59 57 | 3745 | 10.47 | 13 | 13 | 7 | 6 | 7 | 70 | |
| 1319 | 11.2 | 04 11 | -60 57 01 | | 11.96 | 337 | -18 | 1 | 8 | 7 | 57 | |
| 1320 | 11.2 | 04 10 | -60 58 49 | | 11.79 | 191 | 9 | - 9 | 7 | 7 | 77 | |
| 1321 | 10.8 | 04 10 | -60 58 40 | 3743 | 11.82 | 192 | 8 | - 8 | 7 | 8 | 79 | |
| 1322 | 11.8 | 04 10 | -60 56 20 | | 12.69 | 496 | - 4 | - 3 | 12 | 6 | 84 | |
| 1323 | 11.8 | 04 10 | -60 56 51 | | 13.29 | 339 | -17 | -24 | 10 | 10 | 16 | |
| 1324 | 9.0 | 04 06 | -60 57 43 | 3742 | 9.83 | 6 | - 5 | - 1 | 6 | 6 | 84 | |
| 1325 | 10.8 | 04 06 | -60 58 12 | 3740 | 11.11 | 46 | - 3 | 11 | 10 | 7 | 77 | |
| 1326 | 11.2 | 04 06 | -60 57 29 | | 11.61 | 245 | 5 | - 4 | 7 | 6 | 84 | |
| 1327 | 11.6 | 04 06 | -60 56 09 | | 12.42 | 45 | 0 | -10 | 11 | 4 | 81 | |
| 1328 | 9.5 | 04 06 | -60 56 51 | 3738 | 10.30 | 333 | 2 | - 3 | 7 | 4 | 85 | |
| 1329 | 9.0 | 04 05 | -60 58 34 | 3739 | 9.92 | 5 | - 9 | 2 | 7 | 7 | 79 | |
| 1330 | 11.6 | 04 04 | -60 59 57 | | 12.54 | 41 | 0 | 14 | 9 | 9 | 72 | |
| 1331 | 11.8 | 04 04 | -60 59 33 | | 13.13 | 43 | 10 | -35 | 11 | 12 | 5 | |
| 1332 | 9.0 | 04 04 | -60 57 00 | 3738 | 10.20 | 7 | 5 | 17 | 6 | 6 | 62 | |
| 1333 | 11.4 | 04 04 | -60 58 12 | | 12.06 | 39 | 1 | 41 | 8 | 9 | 1 | |
| 1334 | 11.5 | 04 04 | -60 57 10 | | 12.43 | 296 | 11 | -22 | 4 | 9 | 40 | |
| 1335 | 11.8 | 04 02 | -60 58 36 | | 11.41 | 38 | -31 | 3 | 14 | 9 | 7 | |
| 1336 | 11.8 | 04 01 | -60 59 57 | | 13.12 | 40 | 28 | - 9 | 9 | 7 | 16 | |
| 1337 | 11.4 | 04 01 | -60 59 33 | | 12.22 | 42 | 10 | 14 | 6 | 8 | 63 | |
| 1338 | 11.8 | 04 00 | -60 56 55 | | 13.20 | 36 | 22 | - 9 | 8 | 8 | 39 | |
| 1339 | 11.2 | 03 59 | -60 57 34 | | 11.99 | 35 | 6 | -13 | 7 | 8 | 74 | |
| 1340 | 9.5 | 03 58 | -60 56 43 | 3735 | 10.31 | 330 | 11 | 2 | 4 | 6 | 78 | |
| 1341 | 11.3 | 03 57 | -60 59 17 | | 12.13 | 34 | 8 | 9 | 9 | 7 | 76 | |
| 1342 | 10.8 | 03 56 | -61 00 36 | 3732 | 10.92 | 80 | 9 | - 7 | 7 | 5 | 79 | |
| 1343 | 11.6 | 03 57 | -60 56 43 | | 12.52 | 329 | -15 | -32 | 9 | 10 | 5 | |
| 1344 | 9.0 | 03 55 | -60 57 52 | 3731 | 10.00 | 4 | 12 | - 6 | 7 | 6 | 75 | |
| 1345 | 11.8 | 03 55 | -60 59 16 | | 13.02 | 28 | 20 | -27 | 11 | 8 | 8 | |
| 1346 | 11.8 | 03 55 | -60 57 15 | | 12.74 | 33 | 1 | 10 | 14 | 13 | 79 | |
| 1347 | 10.0 | 03 53 | -60 56 24 | 3730 | 10.93 | 31 | - 1 | - 6 | 6 | 7 | 84 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | W No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1348 | 11.2 | 03 51 | -60 59 31 | | 11.81 | 25 | 21 | - 3 | 8 | 6 | 49 | |
| 1349 | 11.8 | 03 49 | -60 58 55 | | 12.73 | 27 | -10 | -29 | 12 | 6 | 14 | |
| 1350 | 11.4 | 03 47 | -60 57 44 | | 12.26 | 507 | 13 | - 5 | 5 | 8 | 74 | |
| 1351 | 10.8 | 03 45 | -60 58 14 | 3729 | 11.25 | 3 | 1 | - 2 | 7 | 5 | 85 | |
| 1352 | 11.8 | 03 45 | -60 57 35 | | 13.08 | 18 | -114 | 31 | 13 | 13 | 0 | 6 |
| 1353 | 11.2 | 03 44 | -61 00 07 | | 12.12 | 103 | 5 | 11 | 7 | 7 | 76 | |
| 1354 | 8.7 | 03 40 | -60 58 25 | 3727 | 9.77 | 2 | 6 | -14 | 5 | 6 | 73 | |
| 1355 | 8.4 | 03 31 | -60 58 43 | 3723 | 9.48 | 1 | 5 | 0 | 7 | 6 | 84 | 1 |
| 1356 | 11.8 | 03 25 | -60 57 29 | | | | - 4 | -17 | 4 | 9 | 66 | |
| 1357 | 11.2 | 03 23 | -60 58 01 | | | | -20 | - 1 | 7 | 8 | 49 | |
| 1358 | 11.8 | 03 19 | -60 56 06 | | | | -50 | -45 | 12 | 11 | 0 | |
| 1359 | 11.3 | 03 18 | -60 57 04 | 3719 | | | 38 | 23 | 10 | 11 | 0 | |
| 1360 | 11.6 | 03 17 | -60 57 08 | | | | 12 | 33 | 11 | 11 | 4 | |
| 1361 | 11.8 | 03 15 | -60 56 15 | | | | -11 | 5 | 9 | 10 | 75 | |
| 1362 | 11.5 | 03 13 | -60 58 50 | | | | 1 | 8 | 7 | 7 | 81 | |
| 1363 | 9.0 | 03 08 | -60 59 27 | 3717 | | | 17 | 5 | 4 | 7 | 61 | |
| 1364 | 11.8 | 03 04 | -60 57 35 | | | | - 9 | 38 | 7 | 7 | 1 | |
| 1365 | 11.4 | 02 51 | -60 59 20 | | | | 9 | 17 | 5 | 8 | 56 | |
| 1366 | 11.8 | 02 35 | -60 56 53 | | | | -141 | -13 | 3 | 9 | 0 | 6 |
| 1367 | 10.7 | 02 32 | -61 00 32 | | | | 25 | - 9 | 8 | 7 | 26 | |
| 1369 | 11.5 | 02 24 | -60 55 54 | | | | - 4 | 0 | 7 | 7 | 84 | |
| 1370 | 10.4 | 02 18 | -60 59 27 | | | | -32 | 14 | 9 | 7 | 3 | |
| 1443 | 10.7 | 06 04 | -60 51 54 | 3785 | | | - 3 | 17 | 7 | 7 | 63 | |
| 1446 | 11.2 | 05 44 | -60 53 31 | | | | 12 | 14 | 6 | 5 | 59 | |
| 1447 | 10.8 | 05 42 | -60 52 24 | 3775 | | | 2 | -14 | 4 | 7 | 75 | |
| 1448 | 9.5 | 05 27 | -60 53 12 | 3769 | | | - 1 | - 2 | 6 | 7 | 85 | |
| 1449 | 10.0 | 05 23 | -60 54 40 | 3767 | | | -63 | 8 | 5 | 5 | 0 | |
| 1450 | 11.8 | 05 16 | -60 51 39 | | | | 81 | -32 | 12 | 12 | 0 | 6 |
| 1451 | 11.0 | 05 03 | -60 55 07 | 3762 | | | -50 | 16 | 8 | 6 | 0 | |
| 1452 | 11.8 | 04 55 | -60 52 35 | | | | -984 | 137 | 19 | 7 | 0 | 6 |
| 1453 | 11.2 | 04 51 | -60 53 58 | | | | 9 | 8 | 8 | 8 | 76 | |
| 1454 | 11.8 | 04 51 | -60 52 07 | | | | 7 | 26 | 6 | 7 | 25 | |
| 1455 | 11.4 | 04 49 | -60 52 50 | | | | -11 | -15 | 8 | 8 | 60 | |
| 1457 | 11.2 | 04 48 | -60 53 02 | | | | -62 | -27 | 8 | 9 | 0 | |
| 1458 | 11.6 | 04 47 | -60 54 22 | | | | 30 | 9 | 10 | 7 | 9 | |
| 1459 | 11.8 | 04 44 | -60 55 32 | | | | 1 | -18 | 14 | 13 | 65 | |
| 1460 | 11.2 | 04 35 | -60 52 44 | 3758 | | | -161 | -23 | 4 | 7 | 0 | 6 |
| 1461 | 11.8 | 04 35 | -60 51 42 | | | | -80 | -23 | 12 | 12 | 0 | |
| 1462 | 11.8 | 04 34 | -60 54 33 | | | | -16 | - 6 | 4 | 5 | 61 | |
| 1463 | 10.8 | 04 26 | -60 51 31 | 3752 | | | 14 | 2 | 6 | 6 | 72 | |
| 1465 | 8.4 | 04 12 | -60 54 35 | 3744 | 9.23 | 8 | -59 | -68 | 6 | 5 | 0 | 6 |
| 1466 | 11.8 | 04 06 | -60 53 17 | | 12.64 | 484 | 2 | -11 | 6 | 10 | 79 | |
| 1467 | 11.8 | 04 02 | -60 54 23 | | 13.30 | 438 | 70 | 40 | 5 | 6 | 0 | |
| 1468 | 11.4 | 03 57 | -60 54 52 | | 11.21 | 37 | -35 | 23 | 8 | 7 | 0 | |
| 1469 | 11.6 | 03 48 | -60 55 32 | | 12.50 | 24 | - 2 | 0 | 6 | 9 | 85 | |
| 1470 | 11.8 | 03 45 | -60 53 43 | | 12.70 | 455 | 52 | 6 | 10 | 6 | 0 | |
| 1471 | 11.2 | 03 42 | -60 51 09 | 3728 | | | 14 | 2 | 7 | 5 | 72 | |
| 1472 | 10.8 | 03 37 | -60 52 52 | 3726 | | | 10 | 1 | 7 | 5 | 80 | |
| 1473 | 11.8 | 03 28 | -60 52 36 | | | | 36 | -16 | 10 | 9 | 1 | |
| 1474 | 11.7 | 03 09 | -60 54 08 | | | | 44 | - 7 | 6 | 12 | 0 | |
| 1475 | 11.8 | 02 56 | -60 53 11 | | | | 9 | 15 | 8 | 9 | 62 | |
| 1476 | 11.8 | 02 52 | -60 53 47 | | | | - 6 | -25 | 7 | 9 | 34 | |
| 1477 | 8.4 | 02 49 | -60 53 10 | 3710 | | | 12 | 8 | 5 | 3 | 71 | |
| 1478 | 8.6 | 02 38 | -60 55 25 | 3706 | | | 7 | 15 | 6 | 8 | 65 | |
| 1479 | 7.5 | 02 33 | -60 54 04 | 3704 | | | -250 | -175 | 10 | 8 | 0 | 6 |
| 1481 | 9.0 | 02 24 | -60 51 08 | 3699 | | | -22 | 8 | 5 | 4 | 34 | |
| 1556 | 11.2 | 06 08 | -60 50 01 | 3786 | | | - 6 | -16 | 8 | 8 | 66 | |
| 1558 | 11.2 | 05 39 | -60 50 15 | 3773 | | | 10 | 18 | 7 | 8 | 51 | |
| 1559 | 8.7 | 05 34 | -60 50 10 | 3772 | | | -324 | -38 | 6 | 6 | 0 | 6 |
| 1560 | 11.8 | 05 27 | -60 47 00 | | | | -21 | -15 | 12 | 10 | 26 | |
| 1561 | 11.8 | 05 16 | -60 50 23 | | | | -39 | -30 | 9 | 8 | 0 | |
| 1562 | 11.4 | 04 12 | -60 46 52 | | | | -145 | -24 | 11 | 9 | 0 | 6 |
| 1563 | 11.6 | 04 12 | -60 48 55 | | | | -21 | 47 | 11 | 10 | 0 | |
| 1564 | 11.8 | 04 03 | -60 46 06 | | | | -53 | 19 | 12 | 10 | 0 | |
| 1565 | 11.2 | 03 59 | -60 49 16 | 3736 | | | -18 | 5 | 8 | 3 | 55 | |
| 1566 | 8.4 | 03 57 | -60 48 20 | 3733 | | | -28 | - 5 | 7 | 6 | 14 | |
| 1567 | 10.8 | 03 33 | -60 47 04 | 3725 | | | 0 | -11 | 7 | 8 | 79 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | W No. | $\mu_x$ | $\mu_y$ | $\sigma_x$ | $\sigma_y$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1569 | 11.6 | 03 05 | -60 49 27 | | | | - 3 | - 7 | 9 | 7 | 82 | |
| 1570 | 11.8 | 03 03 | -60 47 13 | | | | 25 | 14 | 5 | 5 | 16 | |
| 1571 | 11.2 | 03 01 | -60 48 39 | | | | -30 | -15 | 8 | 8 | 4 | |
| 1572 | 11.2 | 03 00 | -60 50 15 | | | | -32 | 18 | 7 | 6 | 2 | |
| 1573 | 10.8 | 02 59 | -60 46 55 | 3715 | | | 3 | -14 | 5 | 8 | 74 | |
| 1574 | 9.2 | 02 51 | -60 47 50 | 3711 | | | -174 | 78 | 8 | 5 | 0 | 6 |
| 1575 | 10.4 | 02 35 | -60 46 11 | 3705 | | | -14 | 8 | 7 | 7 | 64 | |
| 1576 | 10.4 | 02 32 | -60 49 18 | 3703 | | | -446 | 213 | 8 | 6 | 0 | 6 |

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# An Explanation for a Systematic Change in the Plunge of Fold Axes Within an Axial Surface of Constant Orientation

R. J. KORSCH

ABSTRACT. A theoretical model is developed to explain geometrically a systematic change in the plunge of fold axes within an axial surface of constant orientation. If a folded surface was originally horizontal, then as the intensity of folding increases, the dips of the folded surface must become steeper. If the strike of the folded surface is constantly at an angle other than zero to the strike of the axial surface, then as deformation proceeds the dip of the folded surface becomes steeper and the plunge of the fold axis changes from 0° towards 90°. Even a difference of 1° in the strikes of the folded surface and axial surface causes remarkable changes in the plunge of the fold axis, when the dip of the folded surface is close to the dip of the axial surface.

## INTRODUCTION

One problem encountered during field mapping and analysis of structural data from the Coffs Harbour Block in northern New South Wales was to explain why the plunge of D1 mesoscopic fold axes changed systematically while the orientation of the axial surface remained relatively constant. Korsch (1973, Fig. 2B) showed that the plunges of the fold axes were subhorizontal in the northern part of the block and these changed systematically to be steeply plunging in the southern part of the block. This was accompanied by a distinct and progressive tightening of the folds, with the interlimb angles varying from those of open folds in the north to those of tight folds in the south (Korsch, 1973, Fig. 2A).

This problem of the origin of steeply plunging folds is a geological problem difficult of solution, and the problem of explaining a change in the plunge of fold axes has been discussed by many workers. Lillie (1961) proposed two mechanisms for the growth of steeply plunging folds from the Southern Alps of New Zealand, namely the rotation of partly formed folds with continued steepening of the limbs, or the development of new folds on limbs that were already steeply dipping because of an earlier fold episode. He did not envisage any simple rotation of earlier formed folds and attributed the folding to a strike-slip regime associated with the Alpine Fault. Waterhouse (1972), also working in the Southern Alps, invoked the formation of schuppen to steepen the dip and tectonically thicken the sequence, followed by two periods of folding associated with a strike-slip regime in a subduction zone to produce the steeply plunging folds.

Differential flattening in the axial plane or in both the axial and *ac* planes was proposed by Ramsay (1962) to account for fold axes with a variable orientation in theoretical folds of "similar" type. Borradaile (1972) invokes a progressive irrotational constrictive deformation to explain variably oriented folds in the Scottish Highlands. However these folds have a large variation in the plunge of the fold axes. Crosby and Link (1972) invoke stress reorientation to explain curved and steeply plunging fold axes in Wyoming. Roy (1972) interprets variable plunges and trends of the axes of upright folds in western India as a product of the interference of two periods of folding. Garnett and Brown (1973) prefer a single period of protracted heterogeneous strain to produce a progressive change from subhorizontal to steeply plunging mineral-clast lineations and hinge lines, in a constant vertical axial surface, in Canada.

All of the above explanations for a change in the plunge of fold axes, while possibly suitable for the areas where the change was described, are not applicable to the change in the Coffs Harbour Block where the mesoscopic structures present a simple geometrical picture. There is no evidence to indicate a widespread second period of folding, although localised evidence on a small scale was observed. Hence some of the possibilities outlined above are not relevant, and the explanations outlined by Crosby and Link, and Garnett and Brown are considered to invoke stresses of too complex a nature to explain the relatively simple geometry of the mesoscopic structures in the Coffs Harbour Block.

The differential flattening mechanism developed by Ramsay was for "similar" type folds whereas the folds from the Coffs Harbour Block are mainly of "parallel" type (Korsch, 1973). Also, the mechanism refers to changes in plunge within one fold and does not account for progressive changes in the plunge of axes of mesoscopic folds over a distance of several kilometres. Consequently a novel explanation will be outlined in an attempt to offer an alternative solution to this problem.

## THEORY

If one supposes that a folded surface (SF) was originally horizontal, then as the intensity of folding increases, the dips of the folded surface must become steeper, until finally the bedding could become vertical and isoclinal folds could be formed. It is convenient for further analysis to assume that the axial surface (or generated surface, SG) maintains a constant orientation during deformation. Variable factors, upon which the following discussion rely, are:

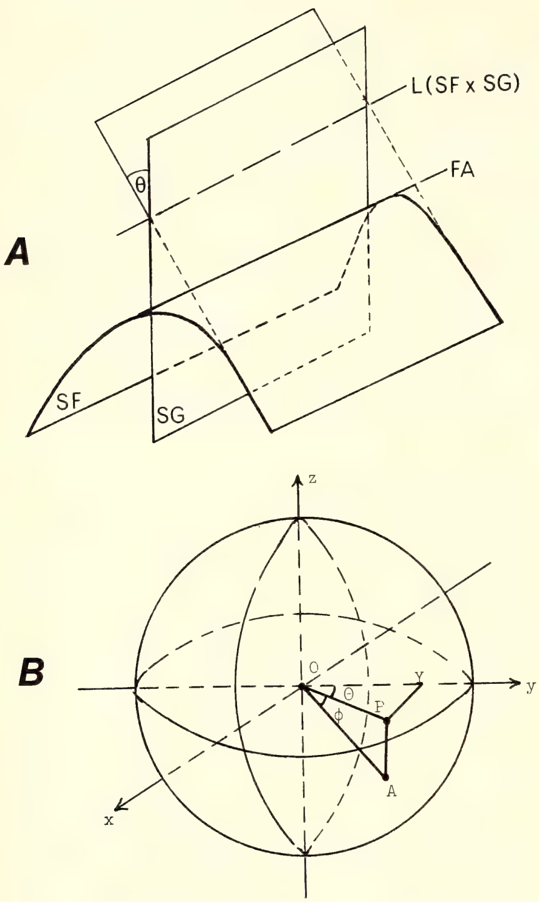



Fig. 1. Diagrams illustrating use of nomenclature and symbols in determining relationships of the marker horizon to the axial surface. For full explanation see text.

a. dip of SF, plus dip direction (only one limb of a fold being considered);

b. angle between the strike of SF and the strike of SG; and

c. plunge and trend of the fold axis (FA).

A special case occurs when the strike of SF is parallel to the strike of SG. As the dip of SF changes, there is then no change in the plunge of FA, which always remains horizontal. In another special case, when SG is horizontal the plunge of FA is again always zero.

The fold axis is determined by the intersection of SF and SG (Fig. 1A). FA is represented by the line OA (Fig. 1B) and its orientation is represented by a plunge (angle $\phi$, from horizontal) and trend (angle $\theta$, from North or y, measured in the horizontal plane). In the general case OA represents the intersection of SF and SG. In the general case OA represents any *B* lineation, including those generated by the intersection of two planes.

Using Fig. 1B, distance OY = y, YP = x, PA = z, OP = p and OA = unity. The direction cosines for the vector OA are: $x = \cos\phi \,.\, \sin\theta$
$y = \cos\phi \,.\, \cos\theta$
$z = \sin\phi$

Using the direction cosines:

1. Plane SF. Using the normal to the plane, trend = $\theta_1$, plunge = $\phi_1$, and direction cosines are:
$$a_1 = \cos\phi_1 \,.\, \sin\theta_1$$
$$b_1 = \cos\phi_1 \,.\, \cos\theta_1$$
$$c_1 = \sin\phi_1$$

2. Plane SG. Using the normal to the plane, trend = $\theta_2$, plunge = $\phi_2$, and direction cosines are:
$$a_2 = \cos\phi_2 \,.\, \sin\theta_2$$
$$b_2 = \cos\phi_2 \,.\, \cos\theta_2$$
$$c_2 = \sin\phi_2$$

Hence the simultaneous equations are:
$$a_1x + b_1y + c_1z = 0 \text{ - - - - - } (1)$$
$$a_2x + b_2y + c_2z = 0 \text{ - - - - - } (2)$$
$$x^2 + y^2 + z^2 = 1 \text{ - - - - - } (3)$$

Using equations (1) and (2),
$$\left.\begin{aligned} x &= k(b_1c_2 - c_1b_2) \\ y &= k(a_2c_1 - a_1c_2) \\ z &= k(a_1b_2 - a_2b_1) \end{aligned}\right\} \text{ - - - - - } (4)$$

Substitute (4) into (3),
$$k = 1/\ (b_1c_2 - c_1b_2)^2 + (a_2c_1 - a_1c_2)^2 + (a_1b_2 - a_2b_1)^2 \text{ - - - - - } (5)$$

By substituting (5) into (4) the values of x, y and z are found. As x, y and z are the direction cosines for the resultant vector OA, the plunge ($\phi_3$) and trend ($\theta_3$) of OA are derived.

By substitution of different values for the plunge and trend of the normals to SF and SG, it is possible to calculate a series of values showing the systematic variation of the plunge of the intersection of the two planes. The results presented in the following discussion have been calculated by computer program SAVSB, information on which can be obtained from the author. An alternative very tedious method is to plot intersections of SF and SG on a stereographic projection to obtain the plunge and trend of the resulting lineation.

Using the results from computer program SAVSB, it is possible to construct a series of graphs for different fixed dips of SG and changing dips of SF. If 10° intervals are used for SG then nine graphs representing the dips of SG from 10° to 90° could be presented, but for brevity only three examples are actually presented, using values for the dip of SG of 90°, 80° and 30° (Fig. 2). On each graph a set of curves shows the changes in plunge of a lineation produced by the intersection of an SF of variable dip and fixed strike with an SG of fixed orientation. The dip of SF on each graph ranges from 0° to 90° in the direction of the dip of SG, and then from 90° to 0° in the opposite direction to the dip of SG. This is represented by the figures 0° to 180° on Fig. 2.

From Fig. 2 it is evident that the plunge of FA is controlled by the dips of SF and SG if the two surfaces have different strikes. Only very

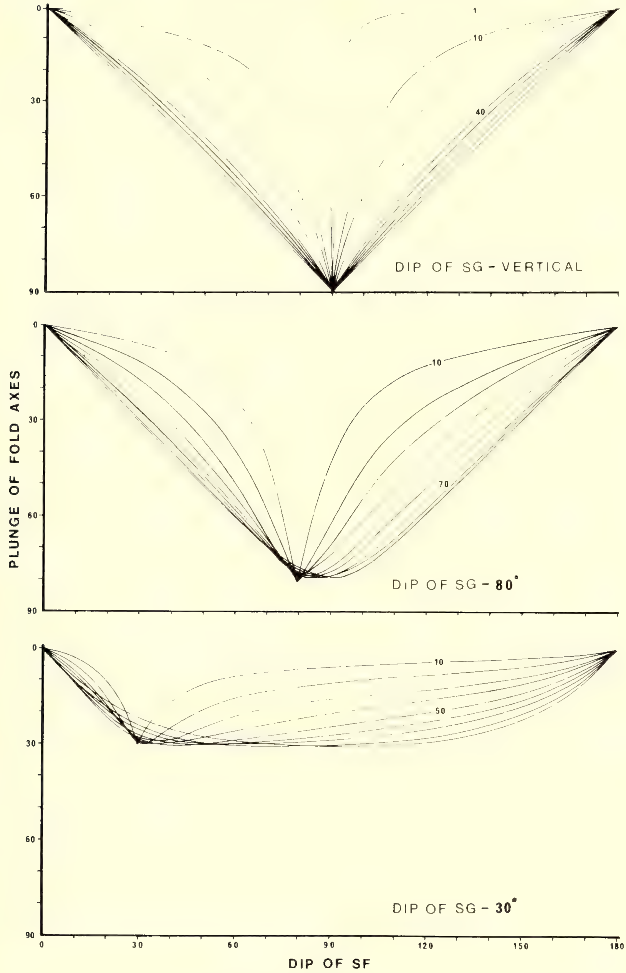
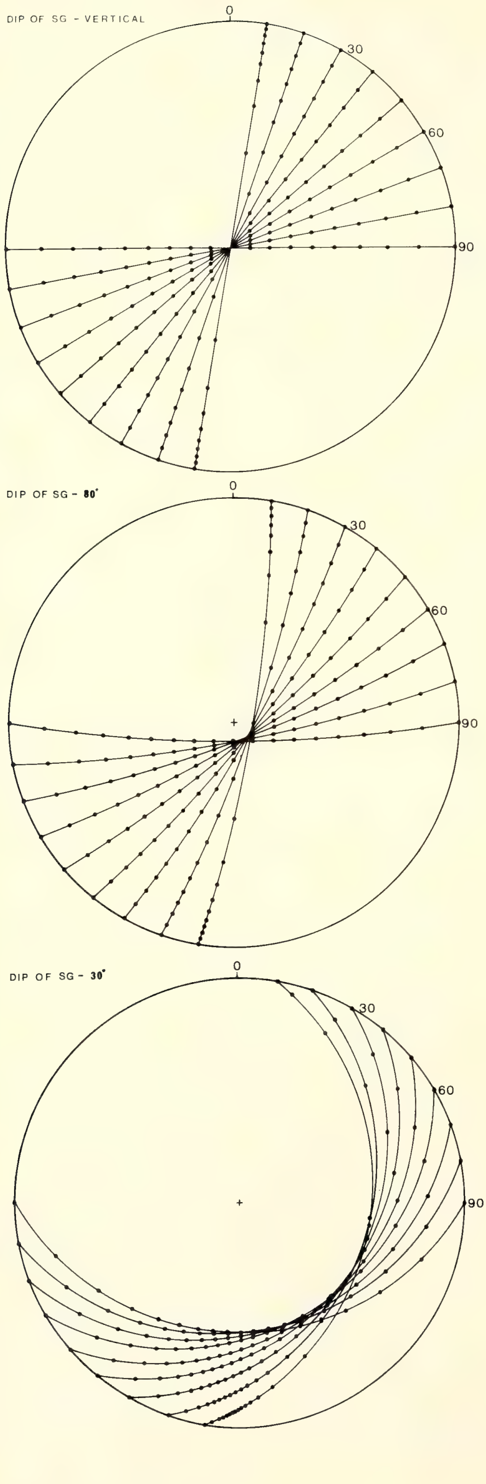



Fig. 2. Change in plunge of an FA produced by the intersection of an SF of variable dip and fixed strike with an SG of fixed orientation. The numbers on the curves (eg. 1, 10, 40 on the top graph) represent the fixed angle between the strike of SF and the strike of SG.

small differences in strike produce effects: even a difference of only 1° causes remarkable changes in the plunge of FA when the dip of SF is close to the dip of SG.

In the general case, if the marker horizon (SF) is horizontal, and a vertical axial surface (SG) develops then the resultant fold axis (FA) is horizontal. If SF is slowly deformed, the limbs of the developing fold become steeper. Keeping SF with a constant strike, it can be seen that the plunge of the FA depends on the dip of SF. Now if the strike of SF is constantly at an angle of 10° to the strike of SG then as deformation proceeds, the dip of SF becomes steeper and the plunge of FA changes from 0° when SF is horizontal to 90° when SF is vertical. Hence it is possible, using the geometric arrangement described above, to have the plunge of FA changing progressively from 0° to 90° even though SG retains a constant orientation. The only constraint is that the strikes of SF and SG must not be parallel.

Figure 3 shows diagramatically the migration of lineations caused by a progressive steepening of a form surface. In the model outlined above the orientation of SG remains constant. However, on the stereographic projections of Fig. 3 the cyclographic traces of SG are shown in different positions for each change in the angle between the




strikes of SF and SG. This is done to avoid overprinting of the movement paths of the lineations.

Sander (1970) briefly outlined the geometry of the intersections of meridians and parallels, and then elaborated to show the changes in the position of *B* if the strike of the s-surface or the axial trend altered. "*If we vary the dip of s from 0° to 90°, the axial plunge with constant axial trend changes at an increasing rate*" (Sander, 1970, p. 167). He was concerned with showing that errors in the measurement of s-surfaces caused large errors in the determination of the plunge of FA, particularly if only a small divergence occurred between the strikes of SF and SG. Apparently he did not realise that his analysis could also solve the problem of changes in plunge that are real (and not artefacts of errors in attitude measurements). The black dots in Fig. 63 of Sander (1970) show the same pattern as in Fig. 3 and his figure is a specific example of the model outlined above (SG vertical SF variable dip and strike).

Ramsay (1967) showed that if the angle between the axial surface of second generation folds and a previously folded surface was small, then any variation in the folded surface could produce a large variation in the direction of the fold axis. Ramsay related this to the direction stability of second generation folds which developed in a previously deformed form-surface, and did not refer to the possibility that it could also solve the change in plunge in first generation folds.

## DISCUSSION

The above theory presents a geometrical solution to the problem but does not take into account the mechanics of the situation. Because SF is being deformed into folds whose axial surface is SG, it is topologically inconsistent in a single folding act for the strike of SF to get far out of parallelism with the strike of SG. The theory will work, however, if there are large volume changes in the hinge regions of the steepening folds. It is also difficult to envisage how the strike of a bed can change with respect to the strike of the cleavage during a single deformation. However a major assumption of the theory is that the strike of SF is kept at a constant angle to the strike of SG, and this angle need be only 1°. If the strikes are not parallel then as the dip of SF steepens, the plunge of the fold axis will change.

The change in the plunge of the fold axis is more pronounced with the steeper the dip of the axial surface. For changes in dip of SF of only 1° or even fractions of a degree there are marked changes in the plunge of the fold axis, and thus infinitesimal strain increments do cause the plunge of the fold axis to progressively increase. Hence within one "domain" the above theory can explain the variations in observed fold axes. It is realised that outside the domain there are mechanical problems, the solution of which might lie on a different scale to the scale of the folds.

Fig. 3. Structural movement paths of lineations for intersection of SF and SG. For full explanation see text.

The geometrical solution outlined above can also be applied to other mechanical situations. For example, if the bedding layers were initially tilted (or had an initial palaeoslope), then bucklefolding (where the generated axial surface is slightly oblique to the strike line of the tilted sequence) could result in steepening fold axes as the deformation proceeds. There would be no need to maintain a constant strike of the folded surface during the tightening of the fold. In the general case this model involves rotation about an axis oblique to the folded surface and therefore there is no need to specify an initial tilting of the folded surfaces.

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# The Use of Amplitude and Wavelength to Compare Successive Folded Surfaces

R. J. Korsch

ABSTRACT. Theoretical models have been developed to explain some systematic changes in the morphology of mesoscopic folds in a field area in northern New South Wales. Equations for determining the wavelength, amplitude and percent shortening in both symmetrical and periodic asymmetrical folds have been derived using the parameters of interlimb angle, chord length and halflength of a fold. Theoretical fold profiles to simulate systematic changes in interlimb angles and chord ratios are useful as a preliminary check in the field to delineate profitable areas for more detailed analysis. Graphs comparing interlimb angles with the amplitude and wavelength ratios of individual form surfaces allow comparisons of the fold shapes produced by different deformational episodes or fold shapes found at different field locations. Significant differences in fold shapes, as determined on the graphs, for folds from two spatially related stratigraphic units from northern New South Wales possibly suggest that the folds developed during two separate periods of deformation.

## INTRODUCTION

It is possible to describe the dimensions of periodic folds by three components: amplitude (A), wavelength ($\lambda$) and interlimb angle ($\theta$), (Fleuty, 1964). The wavelength (Fig. 1) is the length of a periodic unit, measured from one point to the corresponding point on the next fold, and the amplitude is half the perpendicular distance between the two enveloping surfaces. The interlimb angle is "the minimum angle between the limbs, as measured in the profile plane" (Fleuty, 1964, p. 469). This parameter does not define the absolute scale of the fold but can describe the degree of acuteness of the fold.

Matthews (1958) provided a method whereby asymmetrical folds can be described by the short and long limb lengths and axial plane separations for both the short and long limbs. Nevertheless, the terms outlined above are preferred because of their relative simplicity. It is assumed that for symmetrical folds the two limbs are of equal length and the axial surface is normal to the enveloping surface and that for asymmetrical folds the limbs are of unequal lengths and the axial surface is not normal to the enveloping surface.

Assumptions are that for buckle folding the length of the neutral surface (L) within a marker horizon has remained constant throughout the deformation (Ramsay, 1967) and that A, $\lambda$ and $\theta$ have changed systematically. For slip folding it is assumed that $\lambda$ remains constant and L, A and $\theta$ change systematically.

In the general case, it is possible to derive equations for the calculation of $\lambda$, A and percentage shortening (V, defined as original length minus final wavelength, expressed as a percentage of the original length). Furtak & Richter (1967) have provided equations for determining V for angular, circular and rounded folds using the following parameters:

(1) $\alpha$ = angle between tangent to limb and chord of the arc;

(2) a = length of straight portion of limb produced to the point of intersection with the straight portion of the other limb; and

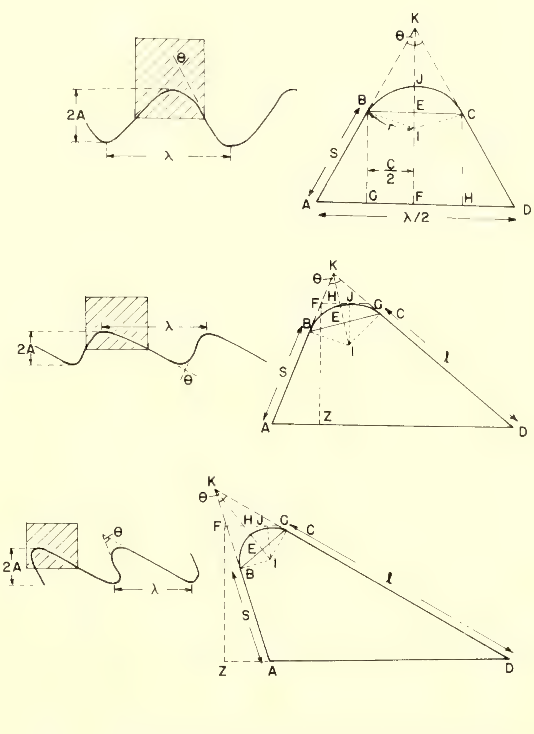


Fig. 1. Dimensions and components of symmetrical folds (A) and asymmetrical folds (B and C).

(3) n = length of straight portion of the limb.

The method presented here differs from that of Furtak & Richter in the choice of the three variables. For symmetrical folds the following variables are used:

(1) $\theta$ = interlimb angle;

(2) c = chord length, that is, length of chord subtending the arc in the fold; and

(3) f = halflength of fold, that is, twice the length of the limb of a fold from the point of inflection to the chord, plus the length of arc.

c and f can be measured in the profile plane in the field using a flexible tape measure, or in the laboratory from a specimen or photograph using a flexible ruler.

It is considered that the parameters described here are easier to measure in the field or derive from photographs or sections measured in the profile plane than are those of Furtak & Richter. The subsequent calculations are more tedious. It is possible to computerise the data, and computer program SHORTNIN, available from the author, provides values of $\lambda$ and V for differing values of $\theta$ and C in symmetrical fold models. C is defined as the ratio of the chord length to the half fold length, that is, C = c/f, and f = L/2. For buckle folds L is the initial length of the fold, often taken as unity.

SYMMETRICAL FOLDS

For symmetrical folds $0 \leqslant C \leqslant 1$ and $0° \leqslant \theta \leqslant 180°$.

From Fig. 1A and using trigonometry,

$$\lambda = 2c + 2f\sin(\tfrac{\theta}{2}) - \left[\frac{180 - \theta}{180}\right] \cdot \frac{\pi c}{2} \cdot \tan(\tfrac{\theta}{2})$$

$$A = \frac{f}{2}\cdot\cos(\tfrac{\theta}{2}) - \frac{(180 - \theta).\pi c}{720} + c/2\cos(\tfrac{\theta}{2}) - \frac{c}{2}\cdot\tan(\tfrac{\theta}{2})$$

To determine "percentage shortening",

$$V = (\frac{L - \lambda}{L}) \text{ x } 100\%$$

This formula determines the total percentage shortening for buckle folds. For flattened buckle folds the calculated V involves the percentage shortening due to buckling, plus a component of shortening related to the flattening, where $\lambda$ decreases as L increases and L is no longer the initial length of the folded layer. For folds involving simple slip parallel to the axial surface, the calculated V gives a measure of the apparent percentage shortening which is not simply related to the true shortening or the true strain within the folded layers.

Since C = c/f, three types of folds can be defined:

(1) C = 0. The folds are angular (chevron) in style. Hence $\lambda = \sin(\frac{\theta}{2})$ and $A = \frac{1}{4}\cos(\frac{\theta}{2})$ because f = L/2, and L is taken as unity.

For folds where C = 0,

(a) as the interlimb angle $\theta$ decreases from 180° to 0° the wavelength decreases in the ratio $\sin(\frac{\theta}{2})$ from 1 to 0.

(b) as $\theta$ decreases from 180° to 0° the amplitude increases in the ratio $\frac{1}{4}\cos(\frac{\theta}{2})$ from 0 to 0.25.

(c) as $\theta$ decreases V increases from 0 to 100% in the ratio $[1 - \sin(\frac{\theta}{2})]$ x 100.

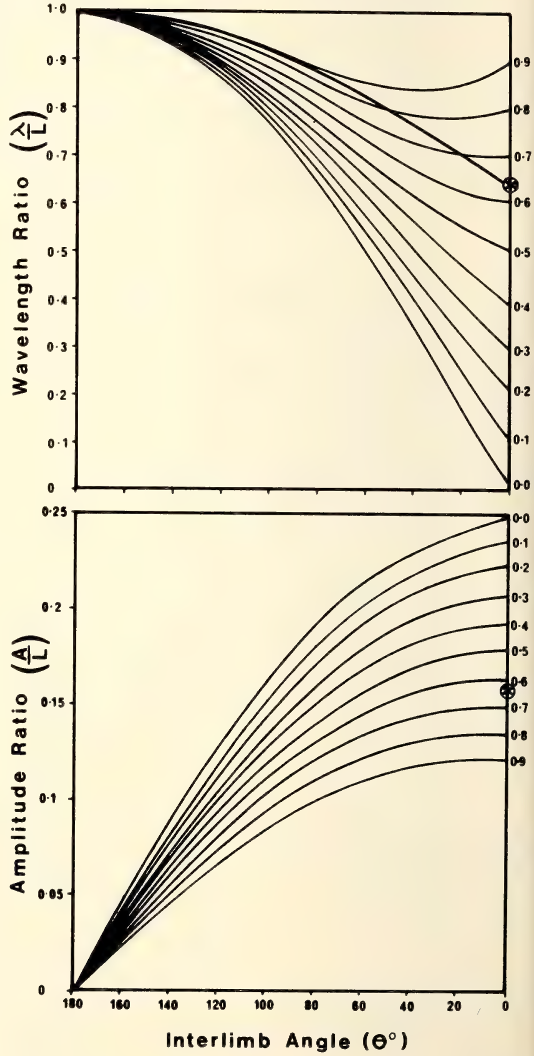


Fig. 2. Values of $\lambda$/L and A/L versus $\theta$ for differing values of C. Heavy line in $\lambda$/L versus $\theta$ graph is curve for $\lambda$ = C. ⊗ is position of pure circular arc parallel folds.

(2) $0 < C < 1$. This is the general case for rounded symmetrical (paraboloidal) folds. A special case occurs when $\theta = 0$ and the folds are semi-circular (de Sitter, 1958). For this special case $\lambda = 2c = 0.64$, $A = 0.16$ and $V = 36\%$, and the folds are in class 1B (parallel folds) of Ramsay (1967).

(3) $C = 1$. For this case $\lambda = L$ and $\theta = 180°$. In other words, the folded surface remains plane and has not been buckled, or deformed in any way.

Results calculated by computer program SHORTNIN have been graphed for differing values of C and $\theta$ (Fig. 2). For circular-arc parallel folds $\theta = 0$ and $V = 36\%$. This plots as a point on the graphs. It is not possible to delineate other classes of folds of the Ramsay classification on the graphs because the graphs are produced for folded surfaces and not for a single layer or groups of layers. An alternative to the graphs of Fig. 2, utilizing $2A/\lambda$ versus V has been used by Currie *et al.* (1962).

The formula for $\lambda$, A and V can be applied not only to buckle and flattened folds but also to folds produced by the slip mechanism and other periodic symmetrical folds, providing the interlimb angle, chord length and half fold length are known. For similar folds $\lambda$, A and $\theta$ remain constant in a stack. However for paraboloidal parallel folds A and $\theta$ vary up and down the stack as $\lambda$ remains constant.

ASYMMETRICAL FOLDS

For periodic asymmetrical folds, using Figs. 1B and 1C, the sine rule, cosine rule and simple trigonometry,

$$\lambda = 2.\sqrt{s^2 + \ell^2 + c.\frac{1 - \cos\theta}{\tan(\frac{\theta}{2})}.(s + \ell) + \frac{c^2(1 - \cos\theta)}{2\tan^2(\frac{\theta}{2})} - 2s.\ell.\cos\theta}$$

$$\text{EXP1} = \text{DAK} = \arcsin\left\{\left[1 + \frac{c}{2\tan(\frac{\theta}{2})}\right].\frac{2\sin\theta}{\lambda}\right\} \quad \text{---(1)}$$

$$\text{EXP2} = \frac{\sin(180° - (\frac{\theta}{2}) - \text{EXP1})}{\sin(\text{EXP1})}.\left[\frac{c}{2\cos(\frac{\theta}{2}).\sin(\frac{\theta}{2})} - \frac{c}{2\cos(\frac{\theta}{2}).\text{cox}(\text{EXP1} + (\frac{\theta}{2}) - 90\ )}\right] \quad \text{---(2)}$$

Using equations (1) and (2):

$$A = \sin(\text{EXP1}).\left[s + \frac{c}{2\tan(\frac{\theta}{2})} - \text{EXP2}\right]$$

Because of the complex nature of these formulae for periodic asymmetric folds, the quickest method of deriving results is to computerise the formulae and insert data for various folds.

Because of space limitations a discussion on the shapes of asymmetrical folded surfaces is not included, but the technique to be followed is the same as presented here for symmetrical folded surfaces. When $s = \ell$ the limbs are of equal length and the fold is symmetrical. A chord ratio, defined as:

$C = c/\ \ s + \ell + \pi c.(180° - \theta)/360\cos(\frac{\theta}{2})$ , can be used to define three types of folds.

(1) $C = 0$, the folds are asymmetrical angular folds.

(2) $0 < C < 1$, this is the general case and the folds are rounded asymmetrical folds.

(3) $C = 1$, here C = total length of fold and is a straight line, $\theta = 180°$ and no folding has occurred.

SHAPE OF FOLDS

The shape of a fold is taken as the shape of the folded layer or layers in the profile plane. Fleuty (1964) considers that fold shapes can be described by the nature of the hinge zone, form of the limbs, and relationship of the two adjoining fold surfaces. Using the values of $\lambda$, A, C and $\theta$ calculated by computer program SHORTNIN, a series of symmetrical folds of varied shapes in the profile plane has been constructed here (Fig. 3). On this diagram two trends in fold shape variation can be delineated:

(1) For a constant $\theta$ there is a spectrum of folds varying from angular towards rounded for differing values of C between 0 and 1. Two special cases occur when $C = 0$ (angular folds) and $C = 1$ (straight line) and the value of C determines the degree of roundness of a fold.

(2) For a constant C there is a spectrum from open to isoclinal folds with differing values of $\theta$ between 0° and 180°. Two special cases occur when $\theta = 180°$ (straight line) and $\theta = 0°$ (isoclinal folds). The interlimb angle determines the degree of acuteness of a fold.

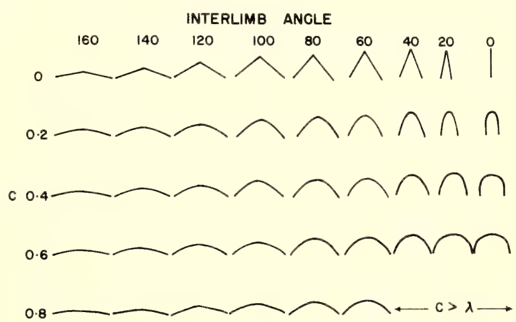


Fig. 3. Shapes of symmetrical folds for changing values of C and $\theta$, using $\lambda$ and A values calculated by computer program SHORTNIN.

For certain values of θ and C a relationship exists where the chord ratio is greater than the wavelength (Fig. 3). This unusual field where $C > \lambda$ might be accounted for by one of the following explanations:

(1) The situation is not real, the folds cannot form, and hence the field is a forbidden one.

(2) Fracturing, shearing or thrusting may occur to compensate for the greater length of the chord. For similar folds (e.g. Dennis, 1967, Fig. 22) as θ approaches zero there is considerable attenuation of the limbs and consequently shearing frequently develops.

(3) The folds might occur only in interference patterns resulting from superposed deformations, or resulting from cross folding during a single period of folding.

Figure 3 is very useful as a chart in the field for making direct visual comparisons with mesoscopic folds in order to determine an approximation of the interlimb angle and ratio of chord length to half fold length. A check of the approximations obtained will then lead to a decision as to whether a full analysis of the shapes might be fruitful.

COMPARISON OF SUCCESSIVE FOLDED SURFACES

The graphs of Fig. 2 can be used to indicate the shape of successive folded surfaces in a folded stack. In theory, for pure circular-arc parallel folds the interlimb angle is zero and the surfaces plot as a point. Similar folds have surfaces which maintain essentially the same shape through the stack and consequently all surfaces will be represented by only one position on the graphs. Of more interest here are surfaces in an idealised paraboloidal parallel folded stack (Fig. 4). These surfaces have a constant wavelength and hence A varies depending on the values of C and θ. However while λ remains constant the ratio λ/L changes for each folded surface up and down the stack, and hence each surface will occupy a different position on the graphs. A progressive change in the position of surfaces 1 to 6 of Fig. 4 occurs on the graph of λ/L versus θ (Fig. 5). Hence the graphs are a useful tool in comparing successive folded surfaces in a stack and progressive variation in fold shape.

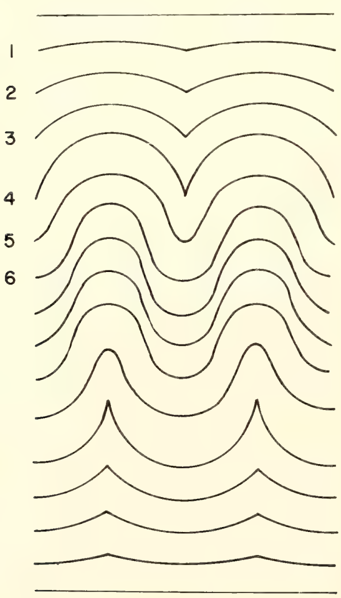


Fig. 4. Theoretical model of an idealised paraboloidal parallel folded stack.

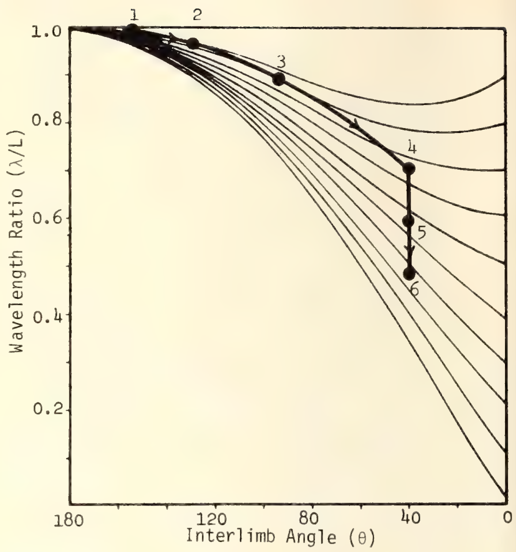


Fig. 5. Migration path of surfaces 1 to 6 of the folded stack illustrated in Fig. 4.

APPLICATION TO A SPECIFIC FIELD PROBLEM

In the Coffs Harbour Block in northern New South Wales, two stratigraphic units consist of very different lithologies and have both suffered the effects of two periods of deformation. The Redbank River Beds (Korsch, 1971) consist of cherts, jaspers and a basic lava in contrast to the Coramba Beds (Korsch, 1978), which are a thick sequence of turbidites consisting predominantly of greywackes with interbedded mudstones, siltstones and minor siliceous units. Macroscopic structural analysis by Korsch (1973) suggests that the deformations in the Redbank River Beds cannot be related to the deformations in the Coramba Beds.

Several representative mesoscopic symmetrical folds from both stratigraphic units were selected for geometric analysis. In the Redbank River Beds the second period of deformation produced only gentle warps which occurred on the limbs of the tight folds, and in the Coramba Beds the second period of deformation produced mainly asymmetrical monoclinal flexuring and kink bands. Hence only folds produced by the first deformations were examined. For eight folded surfaces from three

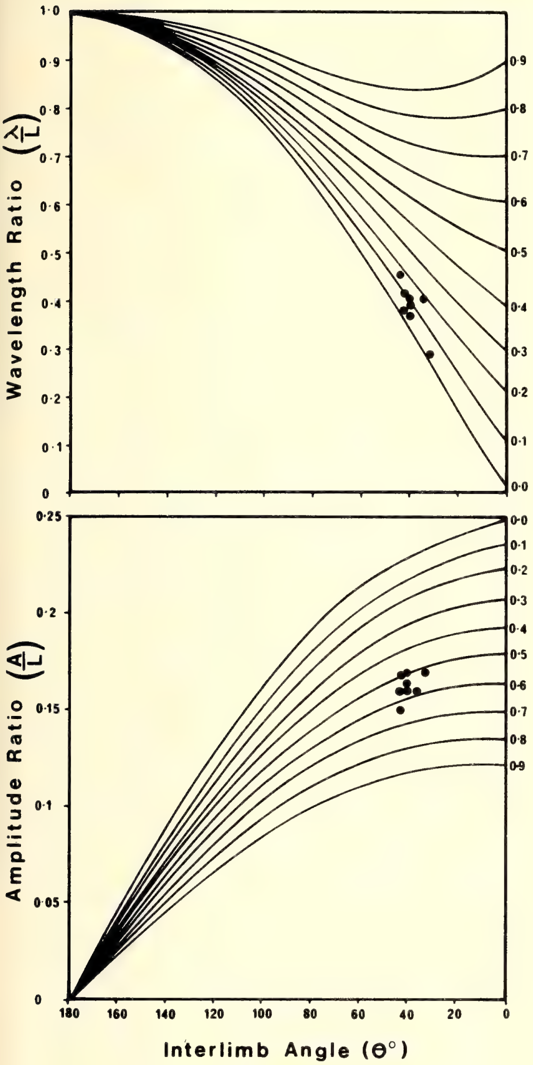


Fig. 6. λ/L and A/L versus θ curves showing positions of eight folded surfaces from three fold stacks in the Redbank River Beds.

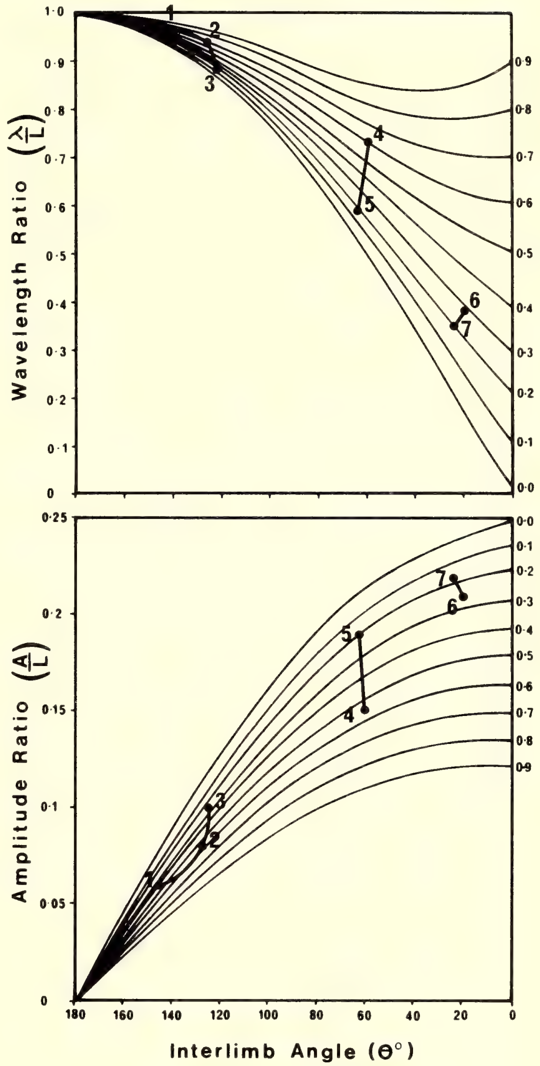


Fig. 7. λ/L and A/L versus θ curves showing positions of seven folded surfaces from three fold stacks in the Coffs Harbour Beds.

separate fold stacks in the Redbank River Beds the ratios of wavelength and amplitude to total fold length (λ/L and A/L, Fig. 6) remain relatively constant even though there are variations in real dimensions. The amplitudes range from 0.2 m to 1.25 m and the wavelengths from 0.33 m to 2.15 m. Interlimb angles are consistent and the low values of C indicate the folds tend towards angularity in the hinges. Hence although the folds vary in size they maintain a constant shape relative to each other.

In the Coramba Beds Korsch (1973) showed that a distinct and progressive tightening of the mesoscopic folds occurs, and that the interlimb angles vary from those of open folds in the north to those of tight folds in the south. This suggests an increase in the intensity of deformation which produced the folds towards the south away from the location of the Redbank River Beds. Most of the folds are symmetrical although a few asymmetrical folds were observed.

Three fold stacks with interlimb angles ranging from gentle (146°) to tight (20°) were selected as representative examples of symmetrical mesoscopic folds produced by the first deformation in the Coramba Beds. The heavy lines joining

numbers on Fig. 7 link surfaces which occur in a single stack. Values for C indicate that the folds are rounded paraboloidal folds. The dispersion of the $\lambda/L$ and $A/L$ values when plotted against $\theta$ on Fig. 7 is such that these folds occupy an extremely large field on the graphs, in contrast with the very limited field for the folds in the Redbank River Beds. Consequently these results support the conclusions of Korsch (1973) that the first deformation of the Redbank River Beds cannot be correlated with the first deformation of the Coramba Beds. In conclusion, the graphs and formulae presented here have practical applications in comparing successive folded surfaces within fold stacks, and as indicators of variability of shape.

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# Palaeomagnetic Results from some Sydney Basin Igneous Rock Deposits

W. A. ROBERTSON

ABSTRACT. The remanent magnetism of nine igneous deposits from the Sydney Basin has been measured and its stability investigated using alternating field and thermal demagnetisation techniques. Variations in the directions of magnetisation demonstrate that the deposits were formed during a number of discrete igneous episodes beginning as early as the Jurassic.

## INTRODUCTION

Many small igneous bodies occur in the Sydney Basin. They form the main reserve of road metal in the Sydney area, and some of the larger deposits contain working quarries, a major source of crushed-rock also used in concrete manufacture. The reserves at the operating quarries are limited and it is important to investigate techniques which bear on the temporal and spatial relationships of the known deposits in order to provide guidelines for future exploration.

This paper presents the results of an investigation into the rock magnetism of some of the deposits, with a view to establishing a chronological classification. A sample of nine intrusives has been studied.

## GEOLOGICAL SETTING

The mainly flat-lying sandstones and shales of the Sydney Basin are cut by many small igneous bodies (Crawford, 1973). These take the form of diatreme-like volcanic necks, dykes and sills. The volcanic necks (Hamilton, 1970) range in size from a few hectares to more than 16 ha, and in composition from volcanic breccia to massive basalt. The dykes, which are commonly basaltic in composition (Crawford, 1973) are less than 2 metres wide, and are not easily seen except on coastal sections.

## PALAEOMAGNETIC PROCEDURES

Samples were collected to cover as wide an area, and hence in most cases as long a time of cooling, as possible, over the outcrop of each occurrence. Core samples were drilled with a 25 mm diameter rock drill, and oriented with a core-orienter and sun-compass using standard techniques (e.g. see Collinson *et al.*, 1967). The cores were sliced into specimens (22 m long) that were measured on a Digico Complete Results Rock Magnetometer. The coercive force spectrum and the related properties of stability of magnetisation were investigated with a Schonstedt alternating field demagnetizer (GSD-1).

Nine deposits were sampled, of which five were volcanic necks, two (Collaroy and Barrenjoey) were dykes, and two (Erskine Park and Kulnura) were sills (see Table 1). A number of specimens, one from each separately oriented drill-core sample (ranging in number from three to sixteen cores from each deposit) were stepwise demagnetised as listed in Table 1. Specimens from the remaining lengths of core were then treated in the field in which the pilot group showed minimum dispersion, shown asterisked, in Table 1 as maximum precision, using Fisher's (1953) best estimate of precision (k).

The blocking temperature temperature spectrum was investigated by treating selected specimens at incremental temperatures up to 700°C, in the

TABLE 1
PRECISION OF PILOT GROUPS AFTER CLEANING IN ALTERNATING FIELDS

| Deposit | N | NRM | 5 mT | 10 mT | 15 mT | 20 mT | 30 mT | 40 mT | 50 mT | 60 mT |
|---|---|---|---|---|---|---|---|---|---|---|
| St Mary's | 16 | 68.9 | - | - | - | 106* | - | - | - | - |
| Hornsby | 6 | 27.7 | 29.6 | 62.6 | 97.9 | 177 | 148 | 266* | 191 | 151 |
| Collaroy | 7 | 17.6 | 43.9 | 124 | 159* | 119 | 13.0 | 13.0 | 2.0 | - |
| Erskine Park | 6 | - | 51.7 | 61.8 | 74.9* | 74.2 | 70.7 | 74.0 | 63.8 | 57.0 |
| Kulnura | 4 | 24.0 | 196 | 280 | 217 | 242 | 202 | 971* | 289 | - |
| Peat's Ridge | 7 | 82.4 | 227 | 315* | 199 | - | 182 | 270 | - | 151 |
| Mogo Hill | 6 | 1.0 | - | 47.0* | - | 9.3 | 8.8 | - | - | - |
| Barrenjoey | 7 | - | 18.5 | 118 | 200* | 155 | 67.9 | 10.2 | - | - |
| Minchinbury | 3 | 215 | 142 | 488 | - | 258 | 2400* | 619 | - | - |

N is the number of specimens used. The headings of the columns are the peak alternating fields used in demagnetising the specimens. The numbers in the columns represent Fisher's (1953) best estimate (k) of the precision of the group about the mean value.

TABLE 2
MEAN DIRECTIONS AND PRECISIONS AFTER OPTIMUM CLEANING

| Deposit | Alternating Field Peak field (mT) | N | D | I | k | $\alpha_{95}$ | S.Pole Position Lat. | Long. | Thermal Temp. (°C) | N | D | I | k | $\alpha_{95}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St Mary's | 20 | 21 | 014 | -81 | 960 | 3.3 | 51 | 144 | 500 | 5 | 028 | -84 | 147 | 6.3 |
| Hornsby | 40 | 6 | 029 | -62 | 191 | 4.8 | 66 | 92 | 400 | 3 | 034 | -60 | 169 | 9.5 |
| Collaroy | 15 | 7 | 322 | -75 | 159 | 4.8 | 53 | 180 | 600 | 4 | 255 | -82 | 28 | 17.6 |
| Erskine Park | 15 | 12 | 184 | -84 | 81 | 4.8 | 23 | 151 | 500 | 4 | 188 | -86 | 78 | 10.4 |
| Kulnura | 40 | 8 | 032 | -62 | 352 | 2.9 | 63 | 91 | 300 | 4 | 032 | -59 | 239 | 5.9 |
| Peat's Ridge | 10 | 14 | 208 | +63 | 333 | 2.1 | 66 | 98 | 300 | 4 | 163 | +63 | 21 | 20.7 |
| Mogo Hill | 10 | 12 | 249 | +84 | 41 | 6.8 | 37 | 138 | 200 | 3 | 305 | +79 | 10 | 40.1 |
| Barrenjoey | 15 | 7 | 142 | +74 | 200 | 4.2 | 53 | 182 | 600 | 3 | 148 | +59 | 5.1 | 60.9 |
| Minchinbury | 30 | 8 | 320 | -75 | 55 | 7.5 | 56 | 179 | 500 | 3 | 290 | -76 | 146 | 10.2 |

N = number of specimens
D = declination
I = inclination
k = precision parameter (Fisher, 1953)
$\alpha_{95}$ = half-angle of cone of confidence at the 95% probability level

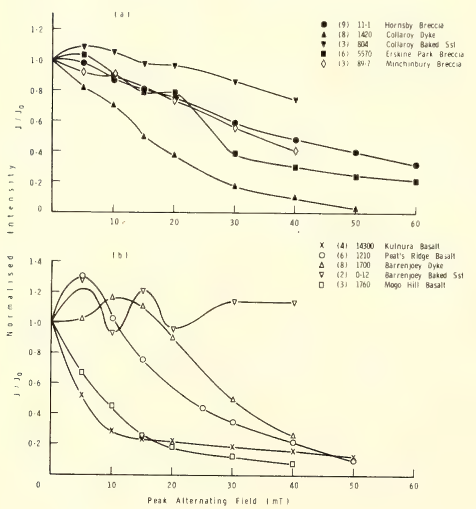


Figure 1. Normalised alternating magnetic field demagnetisation curves for deposits studied. (a) curves for Hornsby, Erskine Park and Minchinbury breccias, Collaroy dyke and Collaroy baked sediment (b) curves for Kulnura, Peat's Ridge and Mogo Hill basalts, Barrenjoey dyke and Barrenjoey baked sediment. Figures in brackets denote number of specimens used in deriving the curves. Unbracketed figures denote mean NRM intensities for same specimens in mA $m^{-1}$ (gauss x $10^{-6}$)

Schonstedt (TSD-1) batch oven. The same minimum dispersion technique was used to obtain the optimum cleaning temperature.

RESULTS

The precision of directions about the mean for pilot groups for each formation (Fisher (1953) k), are given in Table 1 for peak alternating fields up to 60 mT. The fields yielding the maximum precision ranged from 10 mT for Peat's Ridge and Mogo Hill up to 40 mT for Hornsby and Kulnura. The maximum value, asterisked in the table, indicates the appropriate demagnetising field for the remaining material. The resultant mean directions, precision (k) and cone of the half-angle of confidence (Fisher's $\alpha_{95}$) are shown in Table 2.

The magnetic characteristics of the deposits varied greatly. The initial directions from Mogo Hill were random, whereas from St Mary's, Peat's Ridge and Minchinbury they were tightly grouped. Alternating field cleaning improved the precision of directions of all formations. Specimen directions from all the igneous bodies studied grouped with low scatter after cleaning in peak alternating fields of either 10 or 15 mT. It seems likely that much of the initial scatter was caused by soft, viscous components.

The alternating magnetic field demagnetisation curves for each formation, shown in Fig. 1, reveal a wide range of coercivity spectra. The Kulnura and Mogo Hill basalts contain large low coercivity components (Fig. 1b), but they also have high initial intensities and therefore large components remaining in the high coercivity range. The baked sediments at Barrenjoey (Fig. 1b) and Collaroy (Fig. 1a) have very high coervicity components that are thought to be due to the presence of hematite. The increase in intensity for Peat's Ridge after cleaning in an alternating field of 5 mT is thought to be due to the preferential removal of a viscous component in the opposite sense to the reversely magnetised rock. The Hornsby, Erskine Park and Minchinbury breccia

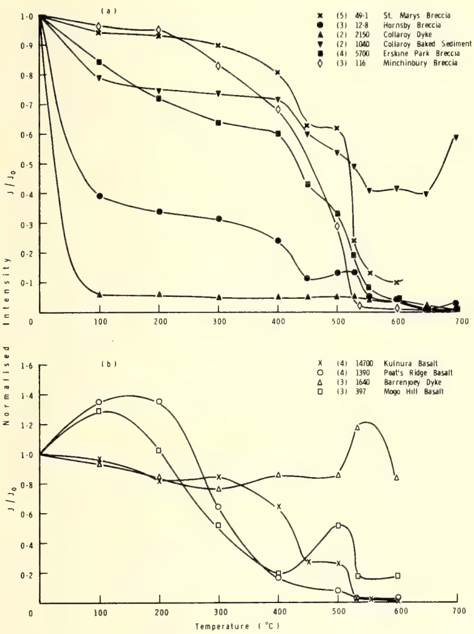


Figure 2. Normalised thermal demagnetisation curves for deposits studied (a) St Mary's, Hornsby, Erskine Park and Minchinbury breccias, Collaroy dyke and Collaroy baked sediment. (b) Kulnura, Peat's Ridge and Mogo Hill basalts and Barrenjoey dyke. Figures in brackets denote number of specimens from which curves were derived. Unbracketed figures denote mean NRM for same specimens in mA $m^{-1}$.

pipes have a wide range of coercivity spectra (Fig. 1a) which may be related to their explosive mode of formation.

Three to five specimens from each deposit were thermally demagnetised in steps (Fig. 2) up to 700°C for Barrenjoey, Mogo Hill and Collaroy baked sediment are thought to be due to chemical alteration during the heating. The increase of intensity for Peat's Ridge and Mogo Hill after cleaning to 100° and 200°C is probably due to the removal of low blocking-temperature components acquired in the present field direction; this opposes the ambient field direction at the time of formation.

The large blocking-temperature components in the range 400° to 550°C for St Mary's, Minchinbury and Erskine Park indicate that these breccias consolidated in temperatures in excess of 400°C, if we assume that the remanent magnetisation is of thermo-remanent origin and acquired when the magnetic crystals cooled through these blocking temperatures. On the other hand, Hamilton *et al* (1970) suggest that, on the evidence of coal reflectance figures from fragments found in these breccias, the temperature of formation must have been less than 100°C. Two possible solutions to this inconsistency may be considered. Firstly, the temperature within the breccias may have varied from less than 100° to more than 400°C at the time of consolidation. Secondly, chemical alterations in the low temperature ranges may have caused the formation of magnetic minerals, most probably iron oxides that acquired a chemical remanence which itself had higher blocking temperatures.

## DISCUSSION

The mean directions for the nine deposits are shown in Fig. 3. All are normally magnetised except Mogo Hill, Barrenjoey and Peat's Ridge, which are reversely magnetised. It is not possible to tell how much of secular variation has been averaged by the time spread of the samples, as the rate at which the acquisition of the magnetisation spread through the deposits is not known. Hence an unknown, but probably small, secular variation error is likely to be present in all the results. Bearing this in mind,

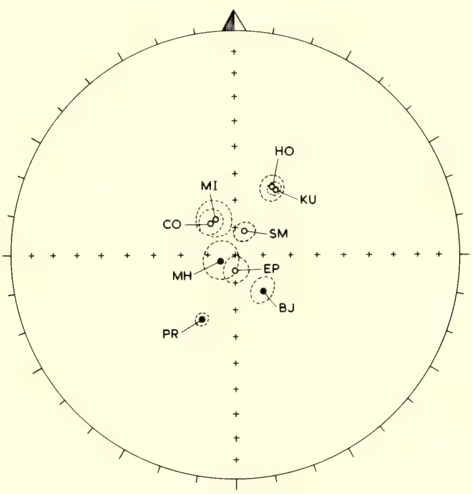


Figure 3. Mean directions of magnetisation for each deposit, using results from the alternating magnetic field that produced the highest precision, plotted on a Schmidt equal area net. Open (solid) circles are north-seeking directions on the upper (lower) hemisphere of the net. Areas outlined in broken lines represent the cones of confidence (Fisher, 1953). BJ = Barrenjoey dyke, CO = Collaroy dyke, EP = Erskine Park sill, HO = Hornsby volcanic neck, KU = Kulnura sill, MH = Mogo Hill volcanic neck, MI = Minchinbury volcanic neck, PR = Peat's Ridge volcanic neck, SM = St Mary's volcanic neck

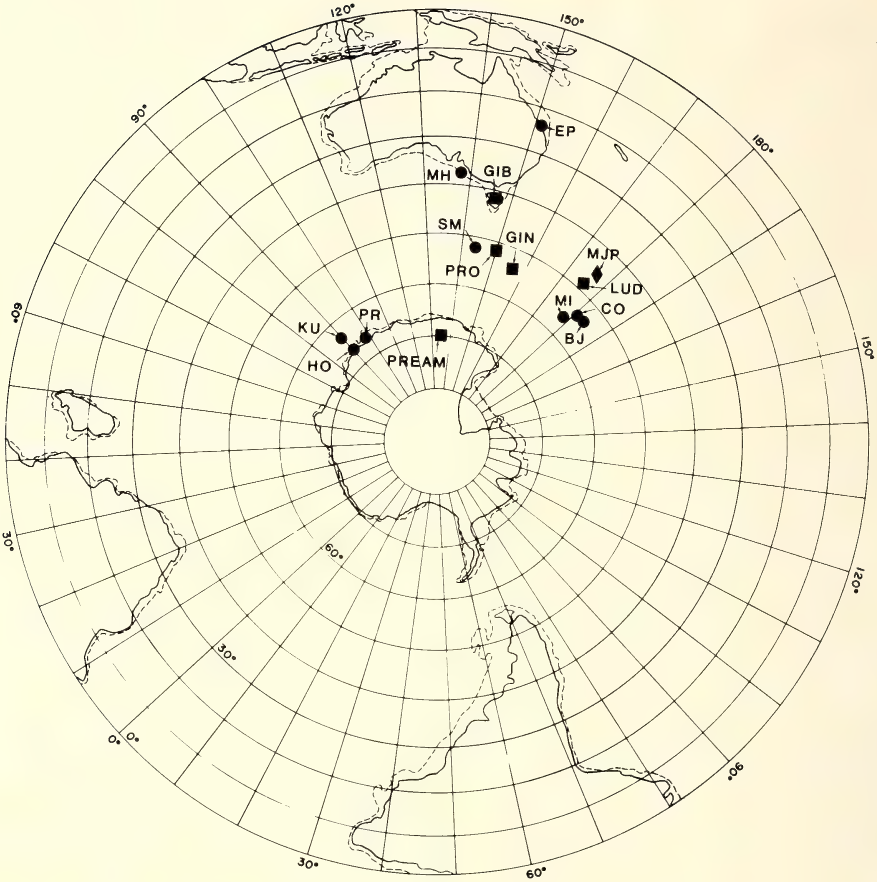


Figure 4. Equal area projection of the southern hemisphere of the earth, showing pole positions calculated from the directions shown in Fig. 3. Also shown are the pole positions for Gibraltar, GIB, Gingenbullen, GIN, and Prospect, PRO (Boesen *et al.*, 1961); Luddenham, LUD, and Peat's Ridge, PREAM (Manwaring, 1963); and the mean Jurassic role (MJP) of Schmidt (1976). MJP now supercedes GIB, GIN and PRO.

the mean directions fall into two distinct groups (Fig. 4). Hornsby, Kulnura and Peat's Ridge form one group, and contain a Tertiary field direction. The fact that the Peat's Ridge direction is reversed indicates that the deposit cannot be exactly contemporaneous with Kulnura and Hornsby but, on the present palaeomagnetic evidence, it is not possible to say which is the older. The other group consists of Collaroy, Minchinbury and Barrenjoey, consistent with a Jurassic age. Pole positions for the deposits at Mogo Hill, Erskine Park and St Mary's are scattered. The intrusions into the Sydney Basin came in several pulses, the first of which was not long after the deposition of the basin. The radiogenic dating of one or more of these palaeomagnetically 'older' intrusions would be of great interest.

Pole positions for other intrusions into the Sydney Basin, of which the directions had been previously determined, (Boesen *et al.*, 1961; Manwaring, 1963) are also shown in Fig. 4.

Gilbraltar, Prospect and Gingenbullen have been radiogenically dated (Evernden and Richards, 1962) and appear to have been intruded during the Jurassic. Recent work by Schmidt (1976) demonstrates that the pole positions from this earlier palaeomagnetic work result from directions in which secondary components have not been entirely eliminated, and his mean Jurassic pole position (MJP), from rocks subjected to more severe laboratory treatment, is also shown in Fig. 4.

The results of this preliminary study show that there are significant differences in remanent magnetisation directions between different intrusions into the Sydney Basin. They are consistent with a hypothesis that the intrusions into the Sydney Basin came in several pulses (Manwaring, 1963) that can be differentiated, in some cases, by differences in their magnetisation directions and the pole positions calculated from them. This technique may -11 provide a simple method of dividing such intrusions into broad age groups.

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# Analysis of the Angular Discordance across the Lambian Unconformity in the Kowmung River — Murruin Creek Area, Eastern N.S.W.

CHRISTOPHER McA. POWELL AND CHRISTOPHER L. FERGUSSON

ABSTRACT. Nineteen measurements of the angular discordance between the Late Silurian to Early Devonian volcaniclastic rocks and the Late Devonian Lambie Group in the Kowmung River - Murruin Creek area range from 8° to 49° with a mean of 24°. This mid-Devonian angular discordance is intermediate between the low-angle discordance found further north in the northeastern Lachlan Fold Belt and the high-angle discordance found near Taralga. These data, considered with data from other areas, suggest that the mid-Devonian angular discordance across the Lambian Unconformity increases southward, and are consistent with the postulate that the northeastern Lachlan Fold Belt is at the perimeter of the area of influence of mid - Devonian deformation that is more intense in the southeastern part of the Lachlan Fold Belt.

## INTRODUCTION

Recent work on the nature of the angular discordance across the Lambian Unconformity in the northeastern Lachlan Fold Belt (Powell and Edgecombe, 1978) shows that where the Lambie Group overlies Early Devonian rocks, the angle of discordance is low. Only 3 of 130 measurements of the discordance exceed 30°, and 2 of the occurrences were in the Kowmung River area at the southern edge of the area mapped. Subsequently, Powell and Fergusson (1979) have shown that in the Taralga area, 50 km further south, the mid-Devonian angular discordance increases to high values that locally exceed 90°. In this paper we analyze angular discordances of intermediate values in the Kowmung River - Murruin Creek area, which lies between the Taralga area and the northeastern Lachlan Fold Belt.

## GEOLOGICAL SETTING

The Early Devonian Lambie Group in the Kowmung River - Murruin Creek area overlies, with erosional unconformity, three major stratigraphic successions (Fig. 1; Scheibner, 1973; Powell *et al.*, 1977): (1) Late Ordovician to Early Silurian quartz sandstone, siltstone and slate (Triangle Group), (2) Late Silurian silicious mudstone and siltstone with minor sandstone and discontinuous limestone and breccia units (Taralga Group), and (3) Early Devonian feldspathic to volcanolithic siltstone, sandstone, boulder conglomerate and lenticle tuff (Kowmung Volcaniclastics, new name - defined in Appendix).

The Triangle Group is multiply deformed, and is separated from the Taralga Group by a high-angle unconformity. Recent mapping shows that the Taralga Group and Kowmung Volcaniclastics, previously shown as being separated by a low-angle unconformity (Scheibner, 1973; Powell *et al.*, 1977, Fig. 4), are actually a conformable succession. The mean grain size and thickness of individual beds increases progressively up-sequence, and the subdivision of the Kowmung Volcaniclastics from the underlying Taralga Group is taken at the base of a thick unit of feldspathic sandstone that can be mapped throughout the area (Fig. 1; *see* Appendix).

Several mappable units occur within the Kowmung Volcaniclastics, and by tracing them we have been able to outline folds that existed prior to deposition of the Lambie Group (Figs. 1 and 2).

Late Silurian fossils have been recovered from the Taralga Group (Scheibner, 1973), and earliest Devonian conodonts from the basal unit of the Kowmung Volcaniclastics (Quilty, 1977, written communication). The basal part of the Lambie Group contains fossil brachiopods and plant stems, and by correlation with nearby areas, is Late Devonian, probably Frasnian (Roberts *et al.*, 1972; Pickett, 1972). The deformation that produced the angular discordance between the Lambie Group and the Kowmung Volcaniclastics is thus mid-Devonian.

## STRUCTURE

The regional structure is part of the meridional latest Devonian to Early Carboniferous folding that affected the eastern Lachlan Fold Belt (Powell *et al.*, 1977). In the Kowmung River - Murruin Creek area, these regional folds trend north to northeasterly, and have a westward-dipping axial-surface cleavage in the fine - grained rocks. Stereograms of bedding show that, in the map area (Fig. 3), the fold axis in the Lambie Group varies from a shallow south-southwesterly plunge (Domain IV) to a gentle north-northeasterly plunge (Domain I). The fold axes in the Kowmung Volcaniclastics (Domains II and III) plunge consistently north - northeast. Just northeast of the map area, the axis of the Kowmung Anticline in the Lambie Group (Fig. 1, inset) plunges 33° towards 026° (Powell and Edgecombe, 1978, Fig. 8).

The average orientation of axial - surface cleavage in Domain III (50° towards 300°) agrees with previous measurements in the Taralga Group and Kowmung Volcaniclastics along Murruin Creek, and has approximately the same orientation as the axial -surface cleavage (56° towards 290°) in the adjacent Cookbundoon Synclinorium (Powell *et al.*, 1977, Fig. 5).

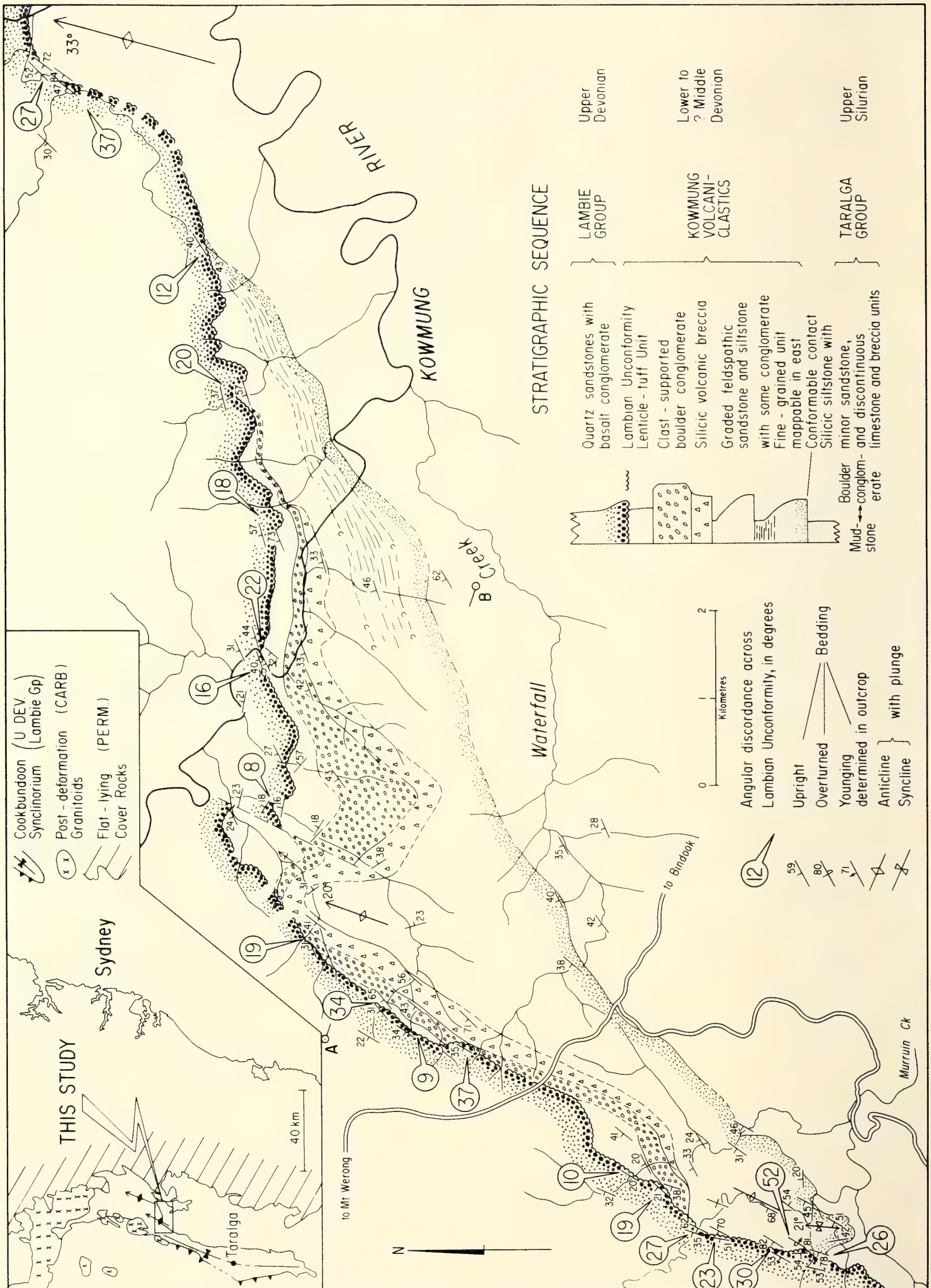



Fig. 1. Geological map of the Lambian Unconformity and subjacent Late Silurian to Early Devonian rocks.

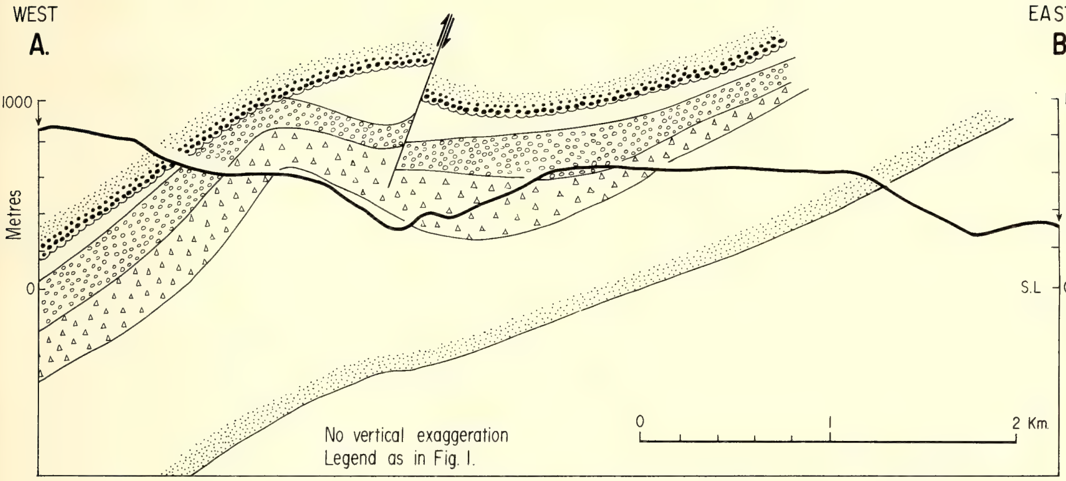



Fig. 2. Cross-section along line A - B in Fig. 1.

The Kowmung Volcaniclastics are preserved in a triangular area with a baseline of 14 km and a structural height of about 1.5 km (Fig. 2). Inspection of the basal Lambie Group shows that any facies changes across the area are slight and gradational, and that there is no evidence that the Kowmung Volcaniclastics formed a hill during deposition of the Upper Devonian. It is thus reasonable to assume that the base of the Lambie Group in the Kowmung River-Murruin Creek area was approximately horizontal, and that consequently the mid-Devonian structure of the Kowmung Volcaniclastics was synclinal with a gently folded enveloping surface. As the map trace of the units within the Kowmung Volcaniclastics shows, there were several low-amplitude parasitic folds of 3 to 4 km wave-length within this broad mid-Devonian syncline, and thus dips on the limbs of the individual parasitic folds were probably steeper than the shape of the enveloping surface.

ANGULAR DISCORDANCES ACROSS THE LAMBIAN UNCONFORMITY

Angular discordances across the Lambian Unconformity have been determined in 19 locations (Fig. 1: Table). Outcrop is good, in many cases approaching continuous exposure in creek beds, and thus the separations between adjacent outcrops either side of the unconformity are small compared with most others previously measured (Powell and Edgecombe, 1978). In 3 locations the unconformity is exposed (Table; Fig. 4; Powell and Edgecombe, 1978, Fig. 9).

The Kowmung Volcaniclastics were restored to their orientation prior to deposition of the Lambie Group using the stereographic technique described by Powell *et al.* (1978, Appendix). The pre-Lambie dips on the Kowmung Volcaniclastics range from $8^{\circ}$ to $49^{\circ}$, with a mean of $24^{\circ}$. When plotted on a stereogram (Fig. 5), the 19 restored bedding poles define a fold axis plunging gently to the west-southwest. As shown from the spread of bedding poles along the $\pi$-circle (Fig. 5), these folds were gentle, with interlimb angles greater than $120^{\circ}$.

DISCUSSION

The angular discordances reported here (19 measurements, ranging from $8^{\circ}$ to $49^{\circ}$, with a mean of $24^{\circ}$) are intermediate in value between the low angles reported further north in the northeastern Lachlan Fold Belt (n=124, range $2^{\circ}$ to $28^{\circ}$, mean $14.5^{\circ}$) and the high angles from the Taralga area (n=11, range $11^{\circ}$ to $132^{\circ}$, mean $55^{\circ}$). This southward increase in the mid - Devonian angular discordance across the Lambian Unconformity is consistent with a similar trend in the Hervey Range - Parkes area (Powell *et al.*, *in prep.*), and suggests that limb dips on mid-Devonian folds increase southward.

The trends of the mid-Devonian folds from the various areas are less consistent. No trend can be deciphered from the restored bedding orientations in the northeastern Lachlan Fold Belt (Powell and Edgecombe, 1978), and the reconstructed mid-Devonian fold axis plunging $14^{\circ}$ towards $253^{\circ}$ in the Kowmung River-Murruin Creek area is nearly at right angles to the mid-Devonian fold trend of $350^{\circ}$ near Taralga (Powell and Fergusson, 1979). Early folds in the Hervey Ranges - Parkes area, if present, trend towards $032^{\circ}$, and are also oblique. Clearly further data from other areas are required to determine whether there is a consistent regional pattern. These angular discordance data support the idea that the northeastern Lachlan Fold Belt is at the perimeter of the area of influence of mid-Devonian deformation that is more intense in the southeastern part of the Lachlan Fold Belt (Powell and Jones, 1978).

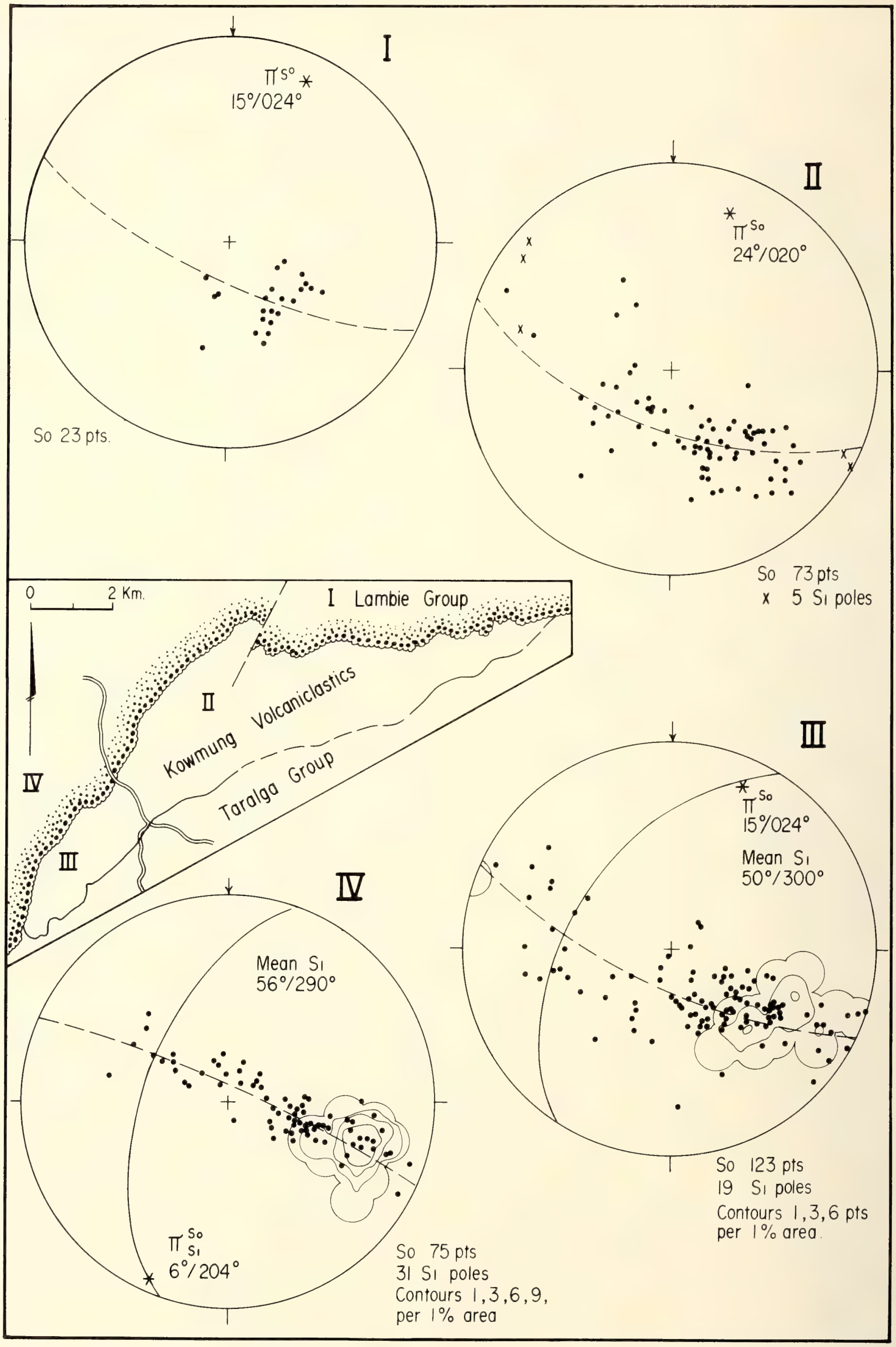
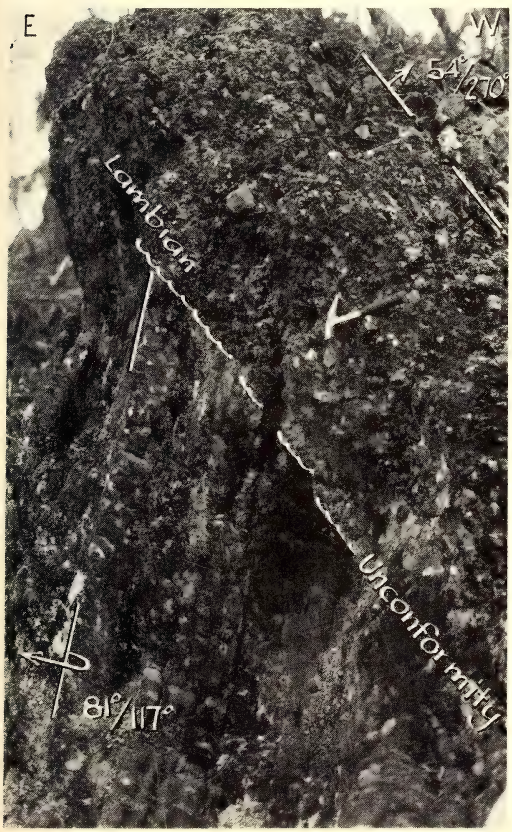



Fig. 3. Equal-area stereograms of bedding ($S_0$) and cleavage ($S_1$) in four domains across the Lambian Unconformity.

TABLE: BEDDING COUPLETS ACROSS THE LAMBIAN UNCONFORMITY

| Location * | | So (U) | So (L) | Regional Fold Axis | Restored So (L) | Comment |
|---|---|---|---|---|---|---|
| Y. | 125 930 | 53/315 | 72/306 | 33/026 | 22/292 | <5 m separation |
| Y. | 125 929 | 47/309 | 84/307 | 33/309 | 31/309 | contact exposed (Powell and Edgecombe, 1978, Fig. 9) |
| Y. | 103 909 | 40/330 | 43/311 | 33/026 | 17/026 | wide separation > 100 m |
| Y. | 084 907 | 37/346 | 57/345 | 33/026 | 17/343 | separation ~ 50 m |
| Y. | 066 903 | 57/347 | 73/340 | 33/026 | 28/354 | separation ~ 50 m |
| Y. | 053 902 | 44/342 | 32/310 | 33/026 | 20/019 | separation ~ 30 m |
| Y. | 052 901 | 40/338 | 25/332 | 33/026 | 19/182 | separation ~ 10 m |
| Y. | 033 901 | 18/032 | 16/010 | 20/024 | 8/262 | separation ~ 60 m |
| Y. | 016 895 | 31/336 | 41/307 | 20/024 | 18/273 | separation ~150 m |
| Y. | 008 886 | 31/332 | 65/321 | 20/024 | 33/321 | separation ~ 50 m |
| Y. | 005 883 | 34/304 | 43/304 | 10/024 | 9/288 | separation ~200 m |
| Y. | 003 876 | 35/300 | 71/315 | 6/204 | 42/328 | separation ~400 m |
| G. | 762 210 | 20/303 | 20/333 | 6/204 | 18/034 | separation ~200 m |
| G. | 761 207 | 21/310 | 38/290 | 6/204 | 17/302 | separation ~100 m |
| G. | 755 203 | 35/290 | 62/295 | 6/204 | 28/302 | separation ~ 60 m |
| G. | 754 200 | 51/280 | 70/296 | 6/204 | 22/304 | separation ~ 50 m |
| Mt. A. | 753 196 | 53/300 | 82/305 | 6/204 | 32/317 | separation < 10 m |
| Mt. A. | 753 192 | 54/270 | 81/117 | 6/204 | 49/296 | contact exposed (Fig. 4) |
| Mt. A. | 752 188 | 53/280 | 78/285 | 6/204 | 27/277 | contact exposed |

* Locations are six-figure grid references to 1:31,800 Yerranderie (Y.) topographic sheet, and to the 1:25,000 Gurnang (G.) and Mt. Armstrong (Mt. A.) topographic sheets. So (U) and So (L) refer to bedding in the rocks above and below the Lambian Unconformity, respectively. The regional fold axis is determined from data in Powell *et al.* (1977), Powell and Edgecombe (1978), and unpublished data, and the method of restoring So (L) to its pre-Late Devonian orientation is outlined in Powell *et al.* (1978).



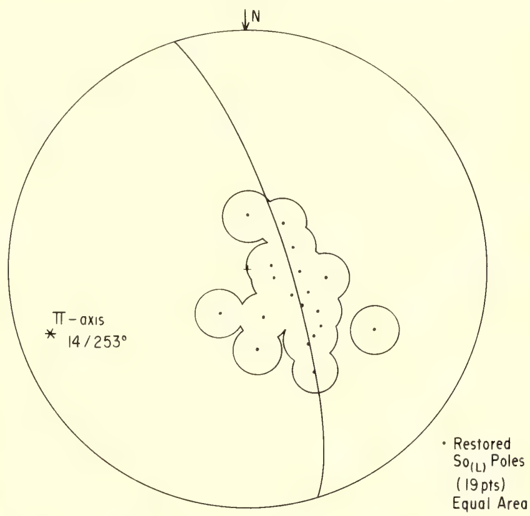




Fig. 5. Equal-area stereogram of bedding poles in the Late Silurian and Early Devonian rocks restored to their presumed orientation prior to deposition of the Lambie Group (*see* Table).

Fig. 4. Lambian Unconformity exposed in Murruin Creek area(Location:753 192 Mt. Armstrong 1:25 000 sheet). The underlying beds are graded feldspathic sandstones facing west (i.e. towards the right in photo), but overturned to dip steeply east (81° towards 117°). The overlying conglomerate contains angular to subrounded cobbles up to 20 cm in diameter, and fines upward into medium-grained, cross-bedded quartzite dipping 54° towards 270°.

ACKNOWLEDGEMENTS

This work was supported by Australian Research Grants Committee, C.S.I.R.O. (Division of Mineral Physics) and Macquarie University. Much of the data were gathered during the Macquarie University field geology course in the period 1976-1978. We thank P. J. Conaghan, J. G. Jones and E. Scheibner for critical comments. Rosemarie Powell typed the final manuscript.

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APPENDIX: DEFINITION OF A NEW STRATIGRAPHIC UNIT

NAME OF UNIT: KOWMUNG VOLCANICLASTICS

DERIVATION OF NAME: Kowmung River (see Yerranderie 1:31800 Topographic Sheet 8929-IV-N).

DISTRIBUTION: The unit is exposed over approximately 20 km$^2$ as a triangular wedge beneath the Late Devonian Lambie Group in the Kowmung River and Murruin Creek area.

TYPE SECTION: The type section is along the Kowmung River from grid ref. 075 889 to grid ref. 053 902 (1:31800 Yerranderie Topographic sheet). Another well-exposed representative section occurs in Cobra Creek, from grid ref. 991 842 (1:31800 Bindook Topographic Sheet 8929-IV-S) to 762 201 (1:25000 Gurnang Topographic Sheet 8829-1-N).

LITHOLOGY: The formation is composed dominantly of coarse quartzo-feldspathic sandstones from a dacitic volcanic source. Boulder detritus and mudstones are lesser components. The grain size and sedimentation-unit size increase upwards to single sedimentation units more than 100 m thick containing boulders. Altered volcanic - glass lenticles and allochthonous limestone blocks are also present.

THICKNESS: Type section 770 metres; Cobra Creek section 820 metres. Maximum preserved thickness probably a little more than 1 km.

RELATIONSHIPS AND BOUNDARY CRITERIA: Overlies conformably mudstones and graded - bedded arenites equivalent to the Late Silurian Taralga Group (Scheibner, 1973). Its base is identifiable by the incoming of the first massive feldspathic sandstones above the mudstones and sandstones of the Taralga Group. It is overlain with medium-angle unconformity by the Late Devonian Lambie Group. The formation is thought to be related genetically to the Bindook Volcanic Complex (Scheibner, 1973).

AGE AND STRUCTURE: Early to possibly Middle Devonian. Conodonts from limestone boulders from the base of the boulder conglomerate member are of earliest Devonian age (Quilty, *pers. comm.*). The overlying Lambie Group elsewhere contains brachiopods of Late Devonian, probably Frasnian age (Roberts *et al.*, 1972), and conodonts of Frasnian age (Pickett, 1972). No other fossils have yet been recovered from the Kowmung Volcaniclastics.

REVISION OF OLD TERMS: The Kowmung Volcaniclastics is a mappable formation, formerly classified within the Bindook Volcanic Complex. Four informal members have been mapped, *viz.* ( bottom to top ) the feldspathic-sandstone member, the silicic volcanic-breccia member, the boulder-conglomerate member and the lenticle-tuff member. The formation is composed dominantly of detritus likely to have been derived from the rhyodacitic to dacitic volcanic complexes near Yerranderie, Bindook and Wombeyan Caves, but as this relation needs to be demonstrated further, it is best mapped as a separate unit.

FURTHER DESCRIPTION: The detailed stratigraphy and sedimentology of the unit will be discussed in Cas *et al.* (in prep.).

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# Folding and Faulting at Brushy Hill, Glenbawn, New South Wales (Discussion)

BRIAN MARSHALL

ABSTRACT. Mory (1978) has suggested that re-activiation of a previously established NNW trending fault is essential if Brushy Hill Fault and Brushy Hill Anticline are to be parts of the same movement-picture. Alternative interpretations of Mory's field relations, based on progressive deformation concepts at high crustal levels, and likely behaviour at the transition from cylindrical to non-cylindrical fold systems, allow the conclusion that Mory's suggestions are possible but not essential.

Mory (1978, Fig. 1 (a) and 1 (b)) has produced an excellent interpretative map of the Brushy Hill area. However, certain of his comments on the structural significance of the map merit additional consideration.

Mory (op. cit., p. 26) refers to an apparent conflict between the suggestion (Branagan et al., 1970; Marshall, 1974) that folding and the Brushy Hill Fault are part of the same movement-picture and:

(i) truncation of the western antiformal hinge line by the Brushy Hill Fault;

(ii) truncation of cross-cutting faults, that post-date the Brushy Hill Anticline, by the Brushy Hill Fault.

Mory suggests that these relations are best reconciled by invoking remobilization of an already established NNW trending fault.

Without wishing to reject Mory's suggestion, I would draw attention to:

(a) the positions and relations of much of the Brushy Hill Fault and most of the apparently truncated cross-cutting faults, relative to the Brushy Hill fold, being largely inferred;

(b) the likelihood that later cross-cutting faults of relatively small displacement (less than 100m) would terminate at the earlier large-displacement (approximately 1000m) Brushy Hill Fault;

(c) the concepts of progressive deformation and brittle-ductile transition (Hobbs et al., 1976), within which evolving overlapping movements on faults and folds at high crustal levels are quite feasible;

(d) having shown that Brushy Hill folding is non-cylindrical in the northern half of the area, that is where the western hinge line is truncated, Mory does not apparently acknowledge the consequences of such inhomogeneity. It is perfectly feasible, particularly where non-cylindrical folds are decreasing in amplitude and plunging out, as is to be expected at the interface between the northern non-cylindrical part of the Brushy Hill fold and the southern cylindrical portion, for hinge line trends to be transgressed by faults of the same movement-picture.

Because of the foregoing items, I suggest that mapped relations at Brushy Hill are compatible with fault and fold having the same movement-sense and being parts of a progressively evolving phase of deformation. Mory's explanation of the relations, and his conclusion that the large displacement on the Brushy Hill Fault is the last deformational event in the area, are possible but not essential.

The constructive comments of G. S. Gibbons, R. Rogerson and C. R. Ward, who critically read the typescript, are acknowledged.

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## VOLUME 112, PART 2

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# Elegance in Molecular Design: The Copper Site of Photosynthetic Electron-Transfer Protein*

HANS C. FREEMAN

ABSTRACT. Plastocyanin is an intensely blue protein which is essential for photosynthesis in green leaves and in some algae. The blue colour is associated with the presence of a single copper atom in each molecule of the protein. In terms of the absorbance per copper atom, plastocyanin is about a hundred times as blue as 'normal' cupric compunds. In addition, the protein has an unusual electron spin resonance spectrum and an anomalously high redox potential. The combination of these properties occurs in some other copper-proteins but has not yet been mimicked in any model compound of low molecular weight.

The recent X-ray crystal structure analysis of plastocyanin has revealed a molecule ideally suited to the biological function which it performs. The nature of the copper site is such as to produce the high redox potential which is required for electron-transfer between plastocyanin and its neighbours in the photosynthetic chain. The location of the copper site in the protein molecule provides at least two reasonable electron-transfer pathways. The exterior of the molecule has distinctive features which suggest that the protein interacts in specific ways with its redox partners and/or its environment.

## INTRODUCTION

I have the honour to be the present custodian of a copy of the Sydney University Calendar issued 100 years ago. This copy is particularly important. The top right-hand corner of the cover bears the signature of *Archibald Liversidge*.

Like all University Calendars, the version of 1878-9 includes a list of the Professors. Liversidge was Professor of Mineralogy, Lecturer in Geology, and Demonstrator in Chemistry. The Hon. John Smith, M.D., was Professor of Chemistry and Experimental Physics. A little while later the Hon. John Smith dropped one of his resonance forms and became simply Professor of Experimental Physics. Liversidge was transformed into the Professor of Chemistry. It is a pity that the increasing complexity of Science and the need for ever greater specialisation have reduced the opportunities for such moves. In these days, when even the adjectives which precede some Chairs of Chemistry are jealously guarded, there is much to admire in the multidisciplinary agility of Sydney's Professors of 100 years ago.

Two pages of the 1878-9 University Calendar are annotated in Liversidge's own hand. On a scale of course fees, the sum of "1 guinea per term" for Mineralogy has been crossed out, and "2 guineas" has been substituted. (Chemistry with Practical Chemistry was rated at 6 guineas.) And on the page of regulations for the conduct of examinations, Liversidge has underlined: *"and the Professor or Lecturer in the School must be satisfied with (the student's) behaviour in class"*! Continuous assessment has been with us for longer than some of us may have suspected.

* *The Liversidge Research Lecture, delivered before the Royal Society of New South Wales, 19th July, 1978.*

The Liversidge Lecture was bequeathed to us so that we might talk about research of the past and research of the future. What I am going to say will involve aspects of chemistry, biology and physics. I should therefore like to begin by establishing a common vocalbulary for what comes later, even though this may involve considerations which many of you will find elementary.

## THE JARGON OF PROTEIN STRUCTURES

A protein is a polymer composed of amino-acid sub-units which differ from one another only by their side-chains, -R (Table 1). There are 24 types of -R which occur naturally. If the 24 natural amino-acids were the letters of an alphabet, then we could use them to write anything from simple words to complicated sentences. Nature uses the 24 amino-acids to assemble a vast variety of molecules representing many levels of complexity.

$$^{+}NH_3\text{-}\underset{R^1}{\underset{|}{CH}}\text{-CO-NH-}\underset{R^2}{\underset{|}{CH}}\text{-CO ----------- NH-}\underset{R^{n-1}}{\underset{|}{CH}}\text{-CO-NH-}\underset{R^n}{\underset{|}{CH}}\text{-COO}^-$$

"Amino terminus" "Carboxyl terminus"

Protein Chemical Structure

The sequence of amino-acids in a protein molecule is called the *primary structure*. The local configuration of the 'back-bone' (the -CONH-CH-CONH-CH-CONH-CH- chain) in a specific region of a protein molecule is called the *secondary structure*. The *tertiary structure* is that arrangement of the primary structure with its elements of secondary structure which minimises the free energy, i.e., it is the molecular structure of the protein.

The best-known element of secondary structure is the α-helix, discovered by Pauling and Corey in the early 1950's. This is a cork-screw arrangement

TABLE 1

SIDE-CHAINS OF SOME IMPORTANT AMINO-ACIDS

| Side-chain (-R) | Amino-Acid Code | Name | Form at pH7, type |
|---|---|---|---|
| Non-functional: Unlikely to interact with metals | | | |
| -H | Gly | Glycine | Non-polar |
| $-CH_3$ | Ala | Alanine | Non-polar, hydrophobic |
| $-CH_2-C_6H_5$ | Phe | Phenylalanine | Non-polar, hydrophobic, aromatic |
| $-(CH_2)_3$-ring from $C_\alpha$ to N | Pro | Proline | Non-polar, hydrophobic, cyclic |
| Functional: Potential metal-binding groups | | | |
| $-CH_2-COO^-$ | Asp | Aspartate | Acidic, hydrophilic |
| $-(CH_2)_2-COO^-$ | Glu | Glutamate | Acidic, hydrophilic |
| $-CH_2-CONH_2$ | Asn | Asparagine | Uncharged, hydrophilic |
| $-(CH_2)_2-CONH_2$ | Gln | Glutamine | Uncharged, hydrophilic |
| $-(CH_2)_4-NH_3^+$ | Lys | Lysine | Basic, hydrophilic |
| $-CH_2-C_3N_2H_3$ | His | Histidine | Basic, pseudo-aromatic |
| $-CH_2-C_6H_4OH$ | Tyr | Tyrosine | Uncharged, polar, aromatic |
| $-CH_2-SH$ | Cys | Cysteine | Uncharged, polar |
| $-(CH_2)_2-S-CH_3$ | Met | Methionine | Non-polar, hydrophobic |

of the protein backbone held together by hydrogen bonds. The side-chains stick out at the sides.

A second important element of secondary structure is one in which the protein backbone is in an extended configuration. Alternate side-chains fall below and above the backbone. If two such backbone segments are adjacent to each other and run in *opposite* directions then there are excellent opportunities for lateral hydrogen-bonding. This arrangement is called 'antiparallel β-structure'. If the adjacent backbone segments run in the *same* direction, the hydrogen bonding is a little less favourable but still effective. We then have 'parallel β-structure'. Several strands of protein backbone may form what is called a 'β-sheet'. Portions of β-sheet frequently occur at the surfaces of protein molecules. The side-chains of each backbone segment then extend alternatively into the solvent and into the 'interior' of the protein.

SOME ASPECTS OF COPPER CHEMISTRY

The aspects of copper chemistry which are most relevant to the present story concern some differences between the two most common oxidation states of the metal, +I and +II. Cu(I) complexes ($3d^{10}$) arr diamagnetic while Cu(II) complexes ($3d^9$) are paramagnetic. In the 'HSAB' (hard-soft-acid-base) classification, Cu(I) is 'soft'. Cu(II) belongs to the 'intermediate' category between 'soft' and 'hard'.

The most common coordination geometry in Cu(I) complexes is tetrahedral. Linear coordination (coordination number 2) also occurs.

The characteristic coordination geometry of Cu(II) is based on an approximately square and planar arrangement of four ligand atoms. In addition there may be *two*, *one* or *no* additional ligand atoms lying on an axis perpendicular to the plan of the other four. The axial bonds, if any, are generally longer than the four 'equatorial' bonds. The resulting geometry is elongated octahedral (two axial ligands), square-pyramidal (one axial ligand) or square-planar (no axial ligand).

The crystal structures of many Cu(II) complexes with amino-acids and peptides (i.e., protein sub-units) have been studied. Some interesting correlations between ligand-types, coordination numbers and spectroscopic properties have emerged (Freeman, 1967; Billo, 1974). On the other hand, we have never been able to crystallise and determine the structures of amino-acid or peptide complexes of Cu(I). Our closest approximation to studying Cu(I) has been a series of structure analyses of the corresponding complexes of another $d^{10}$ metal, Ag(I). The Ag(I) complexes provide examples of linear, trigonal and tetrahedral coordination (Acland and Freeman, 1971; Acland, Flook, Freeman and Scudder, 1972).

SOME PROPERTIES OF COPPER-CONTAINING PROTEINS

Proteins which interact with metal atoms can be divided into two categories:

(i) Proteins which do not contain metal atoms but which are stabilised or potentiated in some way when they combine with metal ions. Such proteins are large organic ligands in equilibrium with metal ions. We shall not consider them further.

(ii) Proteins which have metal atoms as part of their molecular structure: metalloproteins.

The metalloproteins in which the metal is copper have four types of function:

1. Electron transfer.
2. Dioxygen binding.
3. Catalysis.
4. Copper transport.

Functions 1, 2 and 3 all make use of the fact that Cu can exist in two oxidation states which differ by one electron. The number of Cu atoms per protein molecule (or per active subunit where there are several subunits in the molecule) is related to the function of the protein. In electron-transfer Cu-proteins it is 1; in $O_2$-carriers it is 2; in Cu-enzymes it appears to be 1, 2, 4 or 8; and in ceruloplasmin (a protein whose functions include Cu-transport) it is 6 to 8.

The Cu atoms in most Cu-proteins are distinguished by spectroscopic and redox properties which are bizarre in comparison with the behaviour of Cu(I) and Cu(II) in normal (i.e., low-M.W.) complexes. In the present lecture we shall deal with a 'Type 1' Cu centre. There also exist 'Type 2' and 'Type 3' Cu centres. The molecules of some of the multi-Cu proteins contain Cu centres of all three types. We shall concentrate on the electron-transfer Cu-proteins because they contain only one Cu atom per molecule, and that Cu belongs to 'Type 1'.

The properties which distinguish a 'Type 1' Cu centre are:

(a) An absorption maximum near 600 nm with an absorption coefficient $\varepsilon_{max}$ of the order of $5 \times 10^3$ $M^{-1}cm^{-1}$. This value is about 100 times higher than for a typical low-M.W. Cu(II) complex.

(b) An abnormally small hyperfine splitting constant $A_{\parallel}$ in the EPR spectrum. The value of $A_{\parallel}$ for a 'Type 1' Cu-protein is characteristically 0.003-0.008 $cm^{-1}$; for a normal Cu(II) complex it is 0.012-0.020 $cm^{-1}$.

(c) A high redox potential, $E^0$, in the range 0.3-0.8 v, compared with the value 0.17 v. for Cu(I)/Cu(II) couple in aqueous solution.

The property which is most likely to be connected with the biological role of 'Type 1' Cu-centres is the redox potential. The intense blue colour and the small hyperfine splitting constant are useful symptoms which help us to diagnose whether we have a 'Type 1' centre or not, but there is no obvious connection between the blue colour of the EPR spectrum and what the proteins

TABLE 2

PROPERTIES OF 'TYPE 1' ('BLUE') COPPER-PROTEINS

| Protein (Source) | M.W. | $\lambda_{max}$ (nm) / $\varepsilon_{max}$ ($M^{-1}cm^{-1}$) | | | $g_{\parallel}$ | $g_{\perp}$ | $A_{\parallel}$ ($cm^{-1}$) | $A_{\perp}$ ($cm^{-1}$) | $E^o$ (pH) (mV) |
|---|---|---|---|---|---|---|---|---|---|
| AZURIN | 14,000 | 467 | 666 | 820 | 2.26 | 2.05 | 0.006 | ~0 | 300 |
| (*Ps. aeruginosa*) | | 27 | 3500 | 39 | | | | | (7) |
| STELLACYANIN | 20,000 | 450 | 608 | 850 | 2.29 | 2.08, | 0.004 | 0.003, | 184 |
| (*Rhus vernicifera*) | | | 4000 | | | 2.03 | | 0.006 | (7.1) |
| UMECYANIN | 14,600 | 524 | 606 | 787 | 2.32 | 2.05 | 0.004 | — | 283 |
| (Horse radish root) | | 46 | 3400 | 42 | | | | | (7) |
| PLASTOCYANIN | 10,500 | 490 | 597 | 780 | 2.23 | 2.05 | 0.006 | ~0 | 370 |
| (Chloroplasts) | | | 490 | | | | | | (7) |
| BASIC BLUE-GREEN PROTEIN | 10,100 | 443 | 597 | 750 | 2.21 | 2.08, | 0.005 | 0.001, | 317 |
| (Cucumber seedlings) | | | 3500 | | | 2.02 | | 0.006 | (6.8) |

*Includes ~8,000 carbohydrate component

are intended to *do*. The function of Cu-proteins with a single 'Type 1' centre - at least in the cases where we think that the function is understood - is to transfer electrons from one redox partner to another. The property which measures the tendency of a molecule to accept or donate electrons is the redox potential.

A number of single-Cu 'Type 1' proteins are shown in Table 2. *Azurin* is a bacterial electron-transfer protein. *Stellacyanin* is obtained from the Japanese lacquer tree. It is an outlier in the Table because its redox potential is only 0.18 v. *Umecyanin* was isolated from horse-radish in Umeå, Sweden. *Plastocyanin* occurs in the leaves of green plants and in some photosynthetic algae. Finally, a *basic blue-green protein* was isolated at about the same time from cucumber seedlings in California and from cucumber peelings in the U.S.S.R.

## THE CRYSTALLOGRAPHIC STUDY OF PLASTOCYANIN: INTRODUCTION (LENTO) AND SCHERZO (ALLEGRO)

Even at the present time (July 1978), despite intense efforts in a number of laboratories, no one has synthesised any low-M.W. complex which mimics the unusual combination of properties associated with 'Type 1' Cu centres. It was obvious as long ago as 1970 that the 'Type 1' Cu-proteins have properties which are startlingly different from those of simple model compounds prepared from Cu(II) and amino-acids or peptides. The model compounds are capable of providing much useful, precise and fundamental information, but the structure analysis of a 'Type 1' Cu-protein seemed to offer the only chance of discovering what makes the proteins so different from the models.

The choice of plastocyanin for a structure analysis was not an accident. Firstly plastocyanin has all the properties which are characteristic of the 'Type 1' Cu-proteins. Secondly, at the time when we had to make a choice, plastocyanin had the lowest molecular weight of all the 'Type 1' Cu-proteins, so that the number of atoms which we had to find was minimised. (A marginally lower molecular weight was reported a little later for the blue-green protein from cucumbers.) Thirdly, in comparison with the other 'Type 1' Cu-proteins, plastocyanin has a relatively well defined biological function; if the photosynthesists are to be believed, then plastocyanin transfers an electron from cytochrome *f* to pigment P700 in one of the steps between Photosystems I and II. Fourthly and finally, a great deal of information about the amino acid sequences of plastocyanins from higher plants and algae was available even in 1971 from the laboratories of Professor Donald Boulter at Durham and Dr. Richard Ambler at Edinburgh. Much of the primary structure (the amino acid sequence) of plastocyanin was known to be more or less invariant. We hypothesised - correctly, as it turned out - that the variations in primary structure would be unimportant in relation to the function of plastocyanin but would be associated with significant differences in crystallisation behaviour.

Our first step in the structure analysis of plastocyanin was to provide ourselves with the experimental material. The isolation and purification of plastocyanin from French bean leaves had been reported by Milne and Wells (1970) at the University of Adelaide. The Hawkesbury Agricultural College was persuaded to sow a crop of French beans. In due course we harvested the leaves. The first preparation of the protein in our laboratory was carried out late in 1971 by an Honours B.Sc. student, Donald Fensom, with help and advice from a number of our friends (see Acknowledgements).

The early experiments did not yield any crystals, but taught us - inorganic chemists and small-molecule crystallographers that we were - some of the facts of life concerning protein chemistry. Three years, several French bean crops, and three Research Assistants later we obtained our first crystals of French bean plastocyanin. There was a brief period of euphoria when everybody admired the beautiful, deep-blue crystals - followed by a long period of gloom: The crystals were long, thin, fragile needles which were unsuitable for diffraction measurements.

Then started the long search for the ideal vegetable: a plant species which is genetically coded to produce plastocyanin molecules with just the right primary structure to give inter-molecular contacts conducive to good crystallisation. Plastocyanins from thirteen plant species were extracted, purified, and subjected to systematic crystallisation experiments over a wide range of conditions. After a while, our agricultural activities were transferred from the Hawkesbury Agricultural College to the University Research Farms at Camden. Silver beet, cauliflower, carrot tops, lettuce, English spinach, cucumber, zucchini, barley, alfalfa ....

This work owed a great deal to the enthusiasm and persistence of two Research Fellows, Dr. John Ramshaw and Dr. M.P. Venkatappa. John Ramshaw never tired of picking up leaves and extracting plastocyanin from them. 'Ven' Venkatappa carried out most of the painstaking crystallisation experiments.

There came a day when the University gardeners pruned the oleander bushes in front of the Chemistry School. The plastocyanin from the oleander leaves yielded beautiful, chunky, stable crystals. Once again success seemed to be within our grasp, until X-ray diffraction photographs revealed that all the crystals were multiple twins and therefore unsuitable for the structure analysis. We were never able to produce un-twinned crystals of the oleander protein.

The leaves which brought this odyssey to an end came from the poplar trees on the edge of St. Paul's College oval. Poplar plastocyanin yielded large, well-formed crystals (Chapman *et al*, 1977*a*). The crystals were highly stable in the X-ray beam. They gave X-ray reflections at high angles of reflection corresponding to resolution of 1.6A. (Note 1)

There were some uncertainties concerning the antecedents of the poplar trees on St. Paul's oval. It was conceivable that the trees did not belong to the same strain. The crystals used in

the structure analysis were therefore grown from a second batch of protein which was extracted from the leaves of a clone (a genetically homogeneous group) of poplar trees in a State forest at Upper Colo.

The details of the structure analysis (Colman *et al.*, 1978) do not concern us here. The preparation of isomorphous heavy-atom derivatives, the recording of data, the massive calculations, and the fitting of a model to the electron-density map at a resolution of 2.7Å, required a year of intensive work. (Note 2) The persons most directly responsible for the success of the structure analysis are Dr. J. Mitchell Guss and Miss Valerie Norris. It was very helpful, especially in the crucial early stages of the research, that Dr. Peter Colman was working in our laboratory as a Queen Elizabeth II Fellow, so that we could call on his accumulated experience and wisdom.

GENERALITY OF THE STRUCTURAL RESULTS

There is a potential criticism which I should like to answer before I describe the results of the strucutre analysis. It is true that we had indulged in a chemical lottery. We had bet - correctly, as it turned out - that somewhere in the world there was a plastocyanin which would crystallise. Are we entitled to draw any general conclusions about plastocyanin from the structure analysis of the protein from a single plant species chosen in such a haphazard way? The available evidence indicates that we are entitled to do so.

(i) Each plant or other organism which produces plastocyanin is coded so that its plastocyanin has a distinctive aminoacid sequence. The plastocyanin molecule has about 100 residues, and there exist 24 aminoacids. A lot of combinations are theoretically possible. However, not all the possible combinations occur. There are some positions in the protein chain - for example, position 6 - where the same aminoacid is always found. At such a position a particular aminoacid has been ' conserved': The primary structure of the protein has changed in response to evolutionary processes, but residue 6 has never been changed successfully from Gly to anything else. Presumably mutants that have a different aminoacid at residue 6 do not survive. Similarly, all the plastocyanins that are found in Nature now have a Phe at position 41, an Asn at position 38, and so on. There are, in fact, 28 residues *which never vary* (Boulter *et al.*, 1977). If we omit the algal plastocyanins and concentrate on the plastocyanins from higher plants, then there are 55 residues which are invariant and another 15 where the *type* of residue (hydrophobic, acidic, etc.) is conserved.

The invariance of so much of the plastocyanin molecule supports the hypothesis that the structure of *poplar* plastocyanin represents plastocyanins in general.

(ii) Further evidence comes from a long series of high-field $^1$H n.m.r. measurements which Dr. Peter Wright in our Department made last year with the collaboration of Dr. John Ramshaw and Miss Valerie Norris (Freeman, Norris, Ramshaw and Wright, 1978). The proteins used for the measurements were the residues of the earlier unsuccessful crystallisation experiments. The availability of relatively large quantities of plastocyanins from about a dozen different plants turned out to be very useful.

The spectra were recorded both for the reduced (Cu(I)) and oxidised (Cu(II)) forms of each protein. In Cu(I)-plastocyanins the metal is diamagnetic so that all the accessible proton signals are recorded. An immediate conclusion from the spectra of the Cu(I)-plastocyanins is that a great deal of the molecular structure must be the same in all of them. There are certainly some significant differences between the spectra: this is to be expected, since no two plastocyanins have precisely the same aminoacid sequence and hence precisely the same proton environments. Despite these differences, there are many n.m.r. resonances which persist in the spectra of all the Cu(I)-plastocyanins, showing that the environments of many protons are conserved.

In Cu(II)-plastocyanins the metal is paramagnetic. This has the result that the proton resonances are broadened differentially depending on the distances of the protons from the paramagnetic centre. The resonances of protons close to the Cu(II) atom are broadened beyond detection. When the (properly scaled) n.m.r. spectrum of a Cu(II)-protein is computer-subtracted from the spectrum of the corresponding Cu(I)-protein, those resonances which are *not* broadened in the spectrum of the oxidised protein disappear. The resonances which are left in the 'difference spectrum' are those which *are* broadened in the spectrum of the oxidised protein, i.e., the resonances of protons close to the Cu(II) atom.

The n.m.r. difference spectra of a series of plastocyanins are almost identical. This shows that, even though there may be variations elsewhere in the plastocyanin molecules, the environments of the Cu atoms in all of them are effectively the same.

'TYPE 1' Cu CENTRES: EVIDENCE FROM 'SPORTING' METHODS

Even before Dr. Peter Wright's elegant work there had been useful $^1$H n.m.r. experiments on plastocyanin and other 'Type 1' Cu-proteins. Following a visit to our Department by Dr. H.A.O. Hill from Oxford in 1973, Don Fensom (by now a post-graduate student) spent six weeks in Dr. Hill's laboratory during 1974. Working with Dr. Hill and his colleagues, Don Fensom recorded the high-field n.m.r. spectra of Cu(I)- and Cu(II)-plastocyanins at a series of pH's. The chemical shifts of two of the proton resonances in the spectrum of the Cu(I)-protein had pH dependences which suggested that the protons belonged to the imidazole rings of two histidine residues. These particular resonances were among the first to be broadened beyond detectability when the protein was oxidised to the Cu(II) form. More extensive experiments of the same kind were reported by Dr. John Markley at Purdue. This was the first evidence that two imidazole groups are close to the Cu atom (Beattie *et al.*, 1975; Markley *et al.*, 1975).

Applications of other spectroscopic techniques also led to interesting conclusions concerning the Cu site in plastocyanin. In one ingenious experiment, Dr. Harry B. Gray and co-workers at the California Institute of Technology recorded and compared the ESCA spectra of Cu(II)-plastocyanin, Co(II)-substituted plastocyanin and metal-free ('apo-') plastocyanin (Solomon *et al*, 1975). A major peak in the spectrum of apo-plastocyanin was identified as arising from the *2p* electrons of three sulfur atoms. This observation was consistent with the presence of one cysteine and two methionine residues in the aminoacid sequence. The sulfur *2p* peak was reduced by about one-third in the Cu(II)- and Co(II)- plastocyanin spectra; simultaneously a satellite peak appeared, with an integrated area about one-third as large as the original peak. It was concluded that one of the three sulfur atoms in the molecule - probably the thiol sulfur of the cysteine side-chain - is bonded to the Cu atom. It is unfortunate that a subsequent reassessment revealed a flaw in the ESCA experiment and that the original observations have a different explanation.

Nevertheless, at the time when the ESCA results were reported they were consistent with two other pieces of evidence for the involvement of a cysteine thiol group in Cu-binding. Firstly, it had been shown earlier that apo-plastocyanin recombines easily with Cu(II) but that the recombination is prevented by thiol-specific mercurial reagents. Secondly, a thiol-Cu bond could account for the very high extinction coefficient of the absorption band near 600 nm. This band could then be attributed to S $\longrightarrow$ Cu charge-transfer.

The existence of a strong CT chromophore led logically to the recording of resonance Raman spectra for a number of 'Type 1' Cu-proteins. Similar spectra were reported by two laboratories. Dr. T.G. Spiro and co-workers at Princeton interpreted the spectra on the basis of a trigonal-bipyramidal coordination geometry involving four nitrogen or oxygen donor atoms in addition to a cysteine sulfur (Mistowski *et al.*, 1975). Dr. M.N. Young's group at Ottawa obtained an explanation (equally plausible, so far as I can judge) by using a tetrahedral Cu geometry with only three donor atoms in addition to the sulfur (Siiman, Young and Carey, 1976).

The cumulative result of all these experiments was that three of the Cu-binding groups in plastocyanin were tentatively identified as two histidine imidazole groups and a cysteine thiol group. Two further experiments led to the suggestion that the Cu atom forms a fourth bond to the de-protonated nitrogen atom of an amide group in the protein backbone. One of these experiments involved the recording of the infrared spectra of Cu(I)-, Cu(II)-, Co(II)- and apo-plastocyanin (Hare, Solomon and Gray, 1976). Supporting evidence for Cu-amide binding came from the $^{13}C$ n.m.r. difference spectrum for the Cu(I) and Cu(II) forms of a related protein, azurin (Ugurbil *et al.*, 1977) A 1976 'state of the art' diagram of the Cu site in plastocyanin showed an approximately tetrahedral arrangement of a cysteine sulfur, two imidazole nitrogens and amide nitrogen (Solomon, Hare and Gray, 1976).

THE STRUCTURE OF PLASTOCYANIN

On the afternoon of Sunday, September 2, 1977 Mitchell Guss and Valerie Norris finished the job of fitting the first complete model of plastocyanin to the electron-density map at 2.7 Å resolution. The results were telephoned to me in London (where it was still Sunday morning). I spent the rest of the day building a wire model according to the telephoned data. The structure was unveiled at the International Congress on Photosynthesis in Reading three days later (Colman *et al.*, 1977*c*). It was enormously gratifying that the audience included two friends who had in different ways shared the frustrations of the long period when we had no crystals: Dr. Allen Hill, who drove from Oxford, and Dr. John Ramshaw, who flew in from Harvard.

I have said that the structure, in the form in which it was reported at Reading and subsequently published, was solved "at 2.7 Å resolution". It is important for chemists and biologists to appreciate what "2.7Å resolution" means. It means that the structure is viewed as though we used a magnifying glass which can resolve objects only when they are separated by distances larger than about 2.7Å. For example, the carbon atom and oxygen atom of a C=O bond, 1.3Å apart, will not be resolved. On the other hand, the resolution is sufficient to make a distinction between the $-CH_3$ side chain of an Ala and the $-CH_2C_6H_5$ side chain of a Phe, and in many cases there will be bumps in the electron-density at places where the amide C=O groups protrude from the protein backbone.

In the case of plastocyanin, the electron density map at 2.7Å resolution told us what the chemical ligands of the Cu atom are, but did not yield meaningful values for the bond-lengths and bond-angles.

The poplar plastocyanin molecule comprises about 800 atoms. The structure is most easily understood if it is initially represented in a highly idealised way. Let us delete all the side-chains, leaving only the protein backbone; let us then delete the amide groups, leaving only the $C_\alpha$ atoms; let us smoothe out the kinks and irregularities in the chain; and let us finally adapt what is left to the surface of a flattened barrel, which happens to be the regular object that it most closely resembles (Fig. 1).

The molecule is seen to consist of eight strands of protein backbone with bends between the strands. These eight strands form the walls of what we have just described as a barrel. Starting at the $^+NH_3$-end of the protein chain, strand 1 goes up along the front of the barrel. Strand 2 goes down. Strand 3 goes up and over the top, and strand 4 comes down on the other side. Strand 5 (up, at the back of the barrel) is irregular. Strand 6 (down, at the side) leads to a loop under the barrel. Strand 7 (up) ends in the double loop, after which strand 8 continues down to the $-COO^-$ terminus.

The seven strands other than strand 5 have considerable β character. At 2.7Å resolution the details of the hydrogen bonding are not yet defined with precision, but many of the side-chains are clearly visible in the electron-density map. The


Figure 1. Highly schematic representation of the plastocyanin molecule. The $^{+}NH_3$-terminal residue is denoted by N, and the $COO^-$-terminal residue by C. The Cu atom is represented by the black ball.

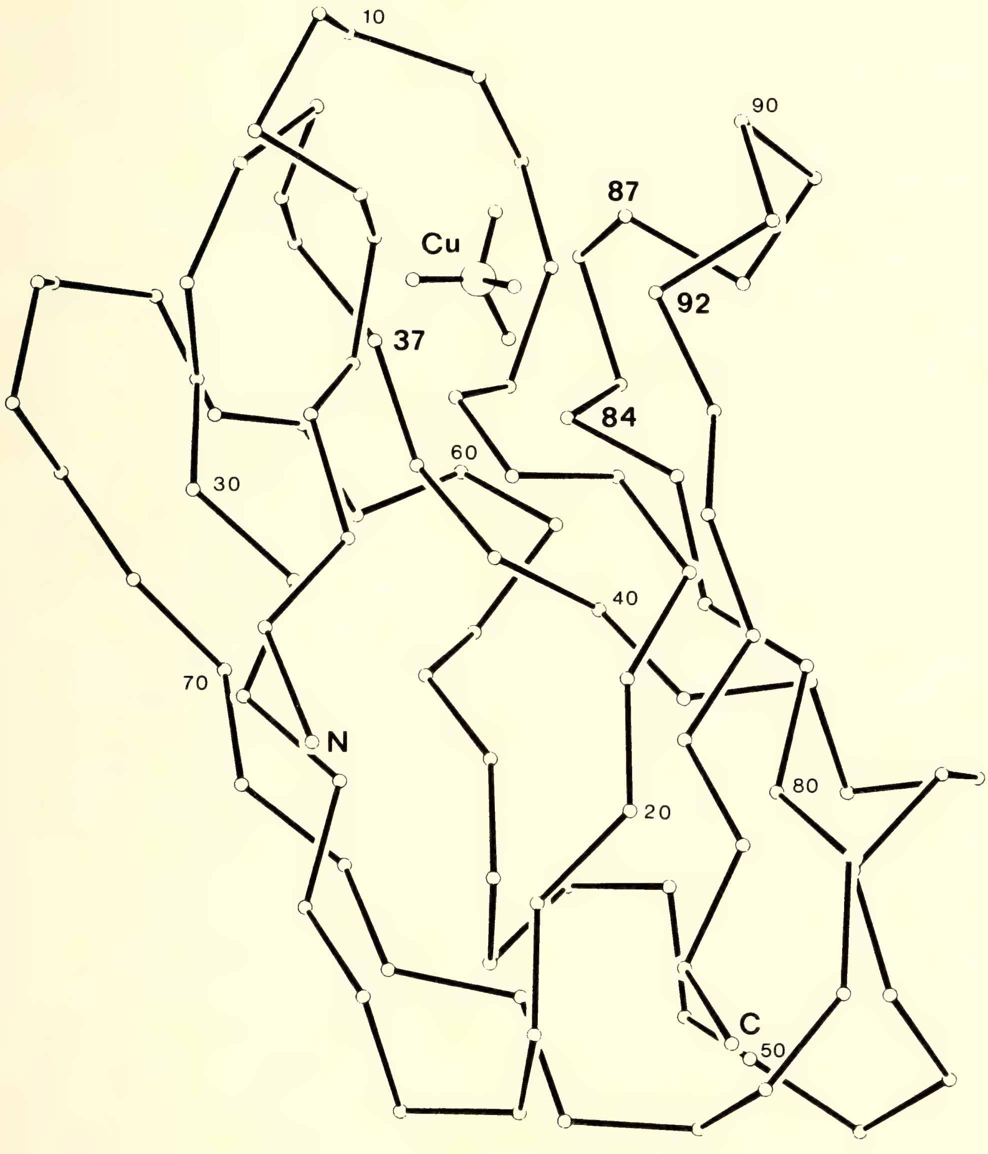


Figure 2. The plastocyanin molecule, drawn by linking the $C_\alpha$ atoms of the 99 amino-acid residues. Small numerals identify every tenth residue. Large numerals identify the four Cu-binding residues. The Cu atom is shown with the four donor atoms to which it is bonded. (This drawing was made in March, 1979 using the atomic coordinates obtained by refinement at 1.6Å resolution.)

evidence for β character is that alternate side-chains appear on opposite sides of the backbone. Strand 5 is quite irregular. It appears to have no β character, and hangs a little outside the rest of the barrel.

The Cu atom lies near one end of the barrel, slightly below the boundary defined by the loop between strands 3 and 4 and the double loop between strands 7 and 8.

Figure 2 is a diagram in which the protein chain is drawn by connecting the actual - not idealised - positions of the $C_\alpha$ atoms. Individual amino-acids are represented by their $C_\alpha$ atoms. Some of them are labelled to indicate their positions in the sequence. The Cu atom is coordinated by the side-chains of residues 37, 84, 87 and 92. The coordination geometry of the Cu atom has been drawn to resemble a tetrahedron, but all that we can say at 2.7Å resolution is that it is irregular: it is less unlike a tetrahedron than it is unlike a square!

The four donor atoms bounded to the Cu atom are

- the δ-nitrogen of the imidazole group of His 37,
- the δ-nitrogen of the imidazole group of His 87,
- the thiol sulfur of Cys 84, and
- the thioether sulfur of Met 92.

The participation of the two His nitrogens and the Cys sulfur is in accordance with the predictions from spectroscopic and chemical observations. The ligand group which surprised almost everybody was Met 92. Indeed, for some days after its discovery as a ligand, the thioether group of Met 92 was a distinct embarrassment. It is worth making a small digression to explain why this was so.

Among the plastocyanins which had been sequenced at Durham was the plastocyanin of a weed called 'dock'. It differed from the other plastocyanins which had been sequenced in having a Leu instead of a Met at residue 92. This result had two possible implications. If, as seemed likely, *all* plastocyanins used the same functional groups to coordinate the Cu atom, then Met 92 could not coordinate the Cu atom in any of them since it was absent in dock. Alternatively, if Met 92 was a Cu-binding residue in one or more plastocyanins, then there was at least one species which had to coordinate the Cu atom in some other way; the generality of the structure analysis of poplar plastocyanin would be lost.

On the Sunday when Mitchell Guss transmitted the structure to me by phone from Sydney to London, he also called John Ramshaw in Cambridge, Mass. Ramshaw took the next convenient flight to England, so as to be present when the structure was announced at the International Congress on Photosynthesis. After arriving in England he called at the University of Durham and, with Professor Boulter's permission, checked the original laboratory records of the aminoacid sequence determination for dock plastocyanin. It turned out that there had been an error in the interpretation of the sequence. Dock plastocyanin, like all the other plastocyanins of which we are aware, has a Met at residue 92.

THE USEFULNESS OF 'MODEL' COMPOUNDS

To what extent could a distorted tetrahedral coordination with two nitrogen and two sulphur donors have been predicted from properties of simpler complexes? In retrospect, all the main features of the Cu coordination in plastocyanin were predictable and had been predicted. What caused difficulties was not a lack of predictions, but an excess.

(i) Several authors had pointed out that there is a possible analogy between the intense visible absorption bands of 'blue' Cu-proteins and the S→Cu charge-transfer bonds of certain Cu(II)-thiol complexes. For example, the structure of a Cu(I), Cu(II) mixed-valence complex of β,β-dimethyl-D-cysteine (D-penicillamine) was solved by Dr. Paul Birker in our laboratory in 1976 (Birker and Freeman, 1977). Each of the six Cu(II) atoms in the complex is coordinated by two thiolate sulphur atoms and two amino groups. The extinction coefficient at 518 nm is about 5000 $M^{-1}cm^{-1}$ per Cu(II) atom.

(ii) The abnormal EPR spectra of 'Type 1' Cu-proteins are another property for which a plausible explanation could be (and had been) found from low-M.W. complexes. Gould and Ehrenberg (1968) in Stockholm examined the effect of irradiating tetrakis-(acetonitrile)-copper(I) perchlorate with γ-rays. The complex is colourless. The Cu(I) atoms are diamagnetic, i.e., they are EPR-inactive. The coordination geometry of the Cu(I) atoms has been shown to be tetrahedral by structure analysis. γ-Irradiation knocked an electron out of some of the Cu(I) atoms, thereby creating Cu(II) centres in tetrahedral environments. The Cu(II) centres were paramagnetic and EPR-active. In the EPR spectrum of the irradiated complex, the hyperfine splitting constant $A_\parallel$ was 0.008 $cm^{-1}$ - at the upper limit for 'Type 1' Cu-proteins, and well below the limit for normal Cu (II) complexes.

(iii) A *number* of reasonable explanations of the high reduction potentials of 'Type 1' Cu-proteins were embodied in a series of $E^o$ measurements for the $Cu^+/Cu^{2+}$ couple in aqueous solutions containing various organic ligands (James and Williams, 1961). In the absence of ligands the value of $E^o$ is 0.167 v. Run-of-the-mill aminoacids cause a drop to negative values since they stabilise Cu(II) by forming excellent chelate complexes. In the presence of imidazole the value of $E^o$ is increased to 0.35 v., close to the values for some of the 'Type 1'Cu-proteins. A high redox potential is also found in the presence of 2,9-dimethyl-1,10-phenanthroline. This ligand and Cu(II) form a strong 2:1 complex in which the normal square-planar coordination geometry of Cu(II) is distorted towards a tetrahedron, due to steric hindrance between the methyl groups of the two ligand molecules. The tetrahedral distortion de-stabilises Cu(II) with respect to Cu(I). Yet another ligand which causes a large increase in $E^o$ is ethylenebisthioglycollic acid, which has two thioether groups. In other words, long-established data on model compounds included evidence that

coordinated imidazole groups *or* coordinated thioether groups *or* a tetrahedral distortion (*or* presumably a combination of any of these factors) are consistent with the high redox potentials of the 'Type 1' Cu-proteins.

(iv) A series of Cu(II) complexes with cyclic thioether ligands had been reported by Dr. David Rorabacher at Wayne State University in 1975 (Jones *et al.* 1975). In these complexes the number of sulfur donors per Cu(II) ranges from 1 to 4. All the complexes have high redox potentials in the same range as the 'Type 1' Cu-proteins, and exhibit intense charge-transfer absorptions (though these occur at slightly shorter wave-lengths than in the case of the proteins). The crystal structure analysis of one complex had shown that the Cu(II) atom has a square-planar geometry. This work had drawn attention to thioether coordination- and had queried the importance of thiol coordination and tetrahedral distortion - as a possible cause of the spectroscopic and redox properties of the 'Type 1' Cu-proteins.

In summary, model compounds would have enabled us to understand the 'Type 1' Cu-proteins if we had known which models we should take seriously.

## ELEGANCE IN MOLECULAR DESIGN

The title of this lecture is 'Elegance in Molecular Design'. Nature 'designs' things by trying out random variations and getting rid of the variants which don't work. In the case of plastocyanin, the result is a splendid example of structure idealised for function. Consider the Cu-binding site (Fig. 3). Above the Cu (or, if you prefer, to the North) lies the imidazole ring of His 87. This is all that separates the Cu atom from the world outside its molecule. Below the Cu (or towards the South, in the direction of the body of the molecule) are the imidazole group of His 37, the thiolate sulphur of Cys 84, and the thioether sulfur of Met 92. How is this combination of ligands related to the function of the protein?

The function of plastocyanin is to transfer electrons. Electron-transfer clearly depends on reversible changes between the two oxidation states of the Cu atom. The first achievement of the molecular design process is that the Cu atom has been given two sulfur donor atoms which are ideal for Cu(I) and acceptable for Cu(II), and two rather basic imidazole nitrogen atoms which are ideal for Cu(II) and acceptable for Cu(I). Changes from Cu(II) to Cu(I) and from Cu(I) to Cu(II) can almost certainly be accommodated by minor local conformational changes, without the breaking and making of metal-ligand bonds. The coordination sphere excellently suits a Cu atom whose purpose in life is to undergo reversible changes in oxidation state.

Reactions in which a metal changes its oxidation state without the rupture or formation of metal-ligand bonds are called "outer-sphere" electron-transfer reactions. Outer-sphere electron-transfer means that two complexes come into sufficiently close contact to establish significant orbital overlap, and that an electron is delocalised from the metal centre of one complex to the metal centre of the other. The 'northern'/edge of the imidazole ring of His 87 would be a useful point of contact between plastocyanin and an outer-sphere redox partner, because the imidazole ring provides a conjugated pathway to and from the Cu atom.

A feature of the Cu site which may make some inorganic chemists feel uneasy is the distorted coordination geometry. We shall not know the precise geometry until the structure is refined, but even at 2.7Å reduction we can see that the coordination of the Cu atom is grossly distorted from the square-planar geometry preferred by Cu(II) towards the tetrahedral geometry preferred by Cu(I). As we have already seen in the case of low-M.W. complexes, a distortion from square-planar coordination geometry increases the redox potential of the Cu(I)/Cu(II) couple, i.e., increases the tendency of Cu(II) to accept an electron. This is just what is needed in plastocyanin, which has to provide the electron-transfer link between two high-potential components of the photosynthetic chain. By the standards of small-molecule geometry, the coordination of the Cu atom is strained; but the strain is built into the Cu site as part of Nature's molecular design.

What is the origin of the strain energy? Protein molecules have more sources of free energy than the small molecules with which inorganic coordination chemists usually deal. A protein molecule has many hydrogen bonds, interactions between side-chains bearing opposite charges, and contacts between hydrophobic groups. Free energy saved in one part of the molecule can be used to pay for strain which is needed in another part. This is the entatic state hypothesis (Vallee and Williams, 1968), and the Cu-binding site in plastocyanin provides a good example of it.

## INVARIANT AMINO-ACID RESIDUES

Special interest is attached to those 55 amino-acid residues which are conserved in the higher plant plastocyanins (Fig. 4). Presumably each one of them is conserved for good reasons. It is possible to test this hypothesis by making a close inspection of the model of the plastocyanin molecule. Let us, however, keep in mind that our present model is fitted to the electron-density at a resolution of only 2.7Å.

(i) Invariant Gly residues.

Nine Gly residues are totally conserved. Another is conserved with only one known exception. Gly residues are subject to fewer geometrical constraints than amino-acids with bulkier side-chains. For this reason they facilitate the formation of bends or turns in the protein backbone. In plastocyanin, nine of the ten conserved Gly residues are found in seven of the bends where the protein chain changes direction (Table 3(a)).

(ii) Invariant Pro residues.

The geometry of Pro is constrained in a special way by the cyclic side chain, so that Pro residues frequently occur at the ends of secondary structures such as α-helices and β-sheets since they cannot be accommodated in the middle. All four conserved Pro residues in plastocyanin occur

TABLE 3

SOME AMINO-ACID RESIDUES WHICH ARE INVARIANT IN HIGHER PLANT PLASTOCYANINS

| | *RESIDUE* | *LOCATION OF RESIDUE OR FUNCTION OF SIDE-CHAIN* |
|---|---|---|
| (a) | Invariant Glycines | |
| | Gly 6, Gly 10 | Bend between strands 1 and 2 |
| | Gly 24* | Bend between strands 2 and 3 |
| | Gly 34 | Bend between strands 3 and 4 |
| | Gly 47 | Bend between strands 4 and 5 |
| | Gly 67 | Bend between strands 5 and 6 |
| | Gly 78 | Bend between strands 6 and 7 |
| | Gly 89, Gly 91 | Bend between strands 7 and 8 |
| | Gly 94 | β-structure |
| | (* Residue 24 in beetroot plastocyanin is Ser.) | |
| (b) | Invariant Prolines | |
| | Pro 16 | Bend in strand 2 |
| | Pro 36 | Beginning of strand 4 |
| | Pro 47 | End of strand 4 |
| | Pro 86 | Loop between strands 7 and 8 |
| (c) | 'Hydrophobic Patch' | |
| | Gly 10 | Rim of Cu pocket |
| | Leu 12 | Rim of Cu pocket |
| | Ala/Val 13 | Rim of Cu pocket |
| | Phe 14 | Side of Cu pocket |
| | Gly 34 | Rim of Cu pocket |
| | Pro 36 | Side of Cu pocket |
| | Leu 62 | Side of Cu pocket |
| | Pro 86 | Rim of Cu pocket |
| | Gly 89 | Rim of Cu pocket |
| | Ala 90 | Rim of Cu pocket |
| | Gly 91 | Rim of Cu pocket |
| (d) | Invariant Polar Uncharged Residues | |
| | Asn 31 | Function ? |
| | Asn 32 | Contact with solvent |
| | Asn 38 | Link from strand 3 to Ser 85 in strand 7 |
| | Ser 56 | Function ? |
| | Asn 64 | Contact with solvent |
| | Tyr 80 | Interior of molecule |
| | Tyr 83 | Contact with solvent near 'negative patch' |
| | Gln 88 | |
| | Thr 97 | Contact with solvent |
| | Asn/Gln 99 | Contact with solvent, $-COO^-$ terminus |
| (e) | Invariant Basic Residues | |
| | Lys 30 | Contact with solvent |
| | His 37 | Cu-binding group |
| | Lys 54 | Contact with solvent |
| | His 87 | Cu-binding group |
| | Lys 95* | Contact with solvent |
| | (* Residue 95 in broad bean plastocyanin is Gln) | |
| (f) | Invariant Acidic Residues | |
| | Asp/Glu 2 | Function ? |
| | Glu/Asp 25 | Contact with solvent |

TABLE 3 (CONT)

| | |
|---|---|
| Asp 42 | |
| Glu 43 | Contact with solvent, side-chains form part of 'negative patch' |
| Asp 44 | |
| Glu 45* | |
| Asp 51 | Contact with solvent |
| Glu 59 | Contact with solvent, side-chains form part of 'negative patch' |
| Asp/Glu 61 | |
| Glu 68 | Function ? |
| Cys 84 | Cu-binding group |

(* Residue 45 is reported to be Ser in poplar plastocyanin)

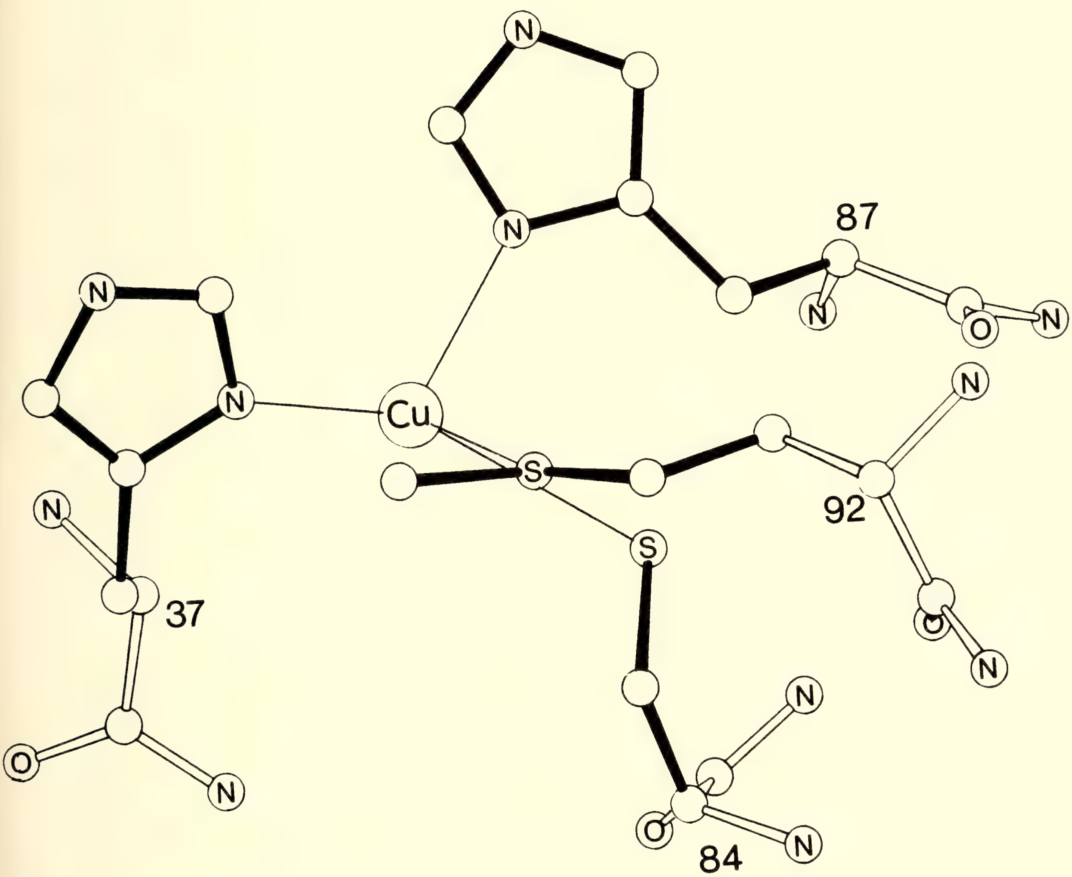


Fig. 3. Detailed view of the Cu atom and the four Cu-atoms binding groups in plastocyanin. Black bonds are in the amino-acid side-chains. Bonds not drawn in black are parts of the protein back-bone.

5 10 15 20 25
ILE-ASP-VAL-LEU-LEU-GLY-ALA-ASP-ASP-GLY-SER-LEU-ALA-PHE-VAL-PRO-SER-GLU-PHE-SER-ILE-SER-PRO-GLY-GLU

30 35 40 45 50
LYS-ILE-VAL-PHE-LYS-ASN-ASN-ALA-GLY-PHE-PRO-HIS-ASN-ILE-VAL-PHE-ASP-GLU-ASP-SER-ILE-PRO-SER-GLY-VAL

55 60 65 70 75
ASP-ALA-SER-LYS-ILE-SER-MET-SER-GLX-GLX-ASX-LEU-LEU-ASN-ALA-LYS-GLY-GLU-THR-PHE-GLU-VAL-ALA-LEU-SER

80 85 90 95
ASN-LYS-GLY-GLU-TYR-SER-PHE-TYR-CYS-SER-PRO-HIS-GLN-GLY-ALA-GLY-MET-VAL-GLY-LYS-VAL-THR-VAL-ASN

POPLAR (POPULUS NIGRA VAR. ITALICA) PLASTOCYANIN SEQUENCE

Figure 4.

The amino-acid sequence of poplar plastocyanin (R. Ambler, personal communication), as used in the analysis of the structure. Some minor ambiguities remain to be resolved (Glx = Glu or Gln, Asx = Asp or Asn). The residues in a few short segments have been ordered by analogy with other plastocyanin sequences.

Doubly underlined residues are conserved in all the higher plant plastocyanins for which we have sequence data. Singly underlined residues are conserved so far as the type of side-chain (acidic, non-polar, aromatic, etc.) is concerned. See, however, Table 3 for notes about residues 24, 45 and 95.

at places where the protein backbone undergoes a turn (Table 3(b)). Two of them, Pro 36 and Pro 86, appear to have a special function which will be mentioned shortly.

(iii) Conserved non-polar residues.

In addition to the four Pro residues mentioned above, there are 22 other conserved non-polar residues (Ala, Ile, Leu, Met, Phe and Val). They include Met 92, one of the four residues to which the Cu is attached. There are another five positions in the sequence which are always occupied by one of the non-polar residues Ala, Ile or Val. In other words, 31 residues are invariant as to hydrophobic character, and 26 of them are totally invariant.

In seventeen cases, the hydrophobic side-chains of these residues point into the interior of the molecule. The molecule is not only a flattened barrel. It is a flattened *oil* barrel. This result is not particularly remarkable. Many other protein molecules are known to have predominantly hydrophobic interiors.

On the other hand, a number of the hydrophobic residues in plastocyanin are associated with a distinctive patch near the Cu site. The Cu atom is located at the bottom of a shallow crater. The rim of this crater is lined by four hydrophobic residues and four Gly's. Three more hydrophobic residues lie on the sides of the crater. All these residues are conserved. They include two of the invariant prolines, Pro 36 and Pro 86 (Table 3(c)). In this region of the molecule there are no charged side-chains at all.

The function of the hydrophobic patch near the Cu site may be *either* to orient the plastocyanin molecule in or on the thylakoid membrane, *or* to make the business end of the molecule recognisable by one or other of plastocyanin's redox partners. The need for a recognition patch is suggested by the high degree of specificity which has been reported to exist between plastocyanin and its natural redox partner, cytochrome *f*. Electron transfer from cytochrome *f* to plastocyanin has been found to be 30 times faster than from any other cytochrome; and electron transfer from cytochromes is generally 1000 times faster than from artificial reducing agents such as inorganic complexes.

(iv) Invariant polar uncharged residues.

There are ten conserved polar uncharged residues (Asn, Gln, Ser, Thr, Tyr) (Table 3(d)). In only one case can we see a clear reason why the residue is conserved: Asn 38 has the C=O of its side-chain amide group hydrogen-bonded to the nitrogen of the backbone amide group of Ser 85. Asn 38 is adjacent to the Cu-binding residue His 37, while Ser 85 is adjacent to the Cu-binding residue Cys 84. The side-chain of Asn 38 thus stabilises the configuration of the Cu-site by linking two strands of the protein backbone near two of the Cu ligands.

Six of the remaining conserved polar uncharged residues appear to be in contact with the solvent. Two of them, Tyr 83 and Gln 88, will be mentioned again later in connection with the 'negative patch' on the plastocyanin molecule. The side-chain of Tyr 80 points to the interior of the molecule.

(v) Invariant basic residues.

The amino-acids which have ionisable side-chains are distributed unequally throughout the plastocyanin molecule. In poplar-plastocyanin there are only six basic residues: two His and four Lys. Five of these residues are conserved in higher plant plastocyanins (Table 3(e)). They are (i) His 37 and His 83, which bind the Cu atom through their imidazole groups, and (ii) Lys 30, Lys 54 and Lys 95, which point from the surface of the molecule into the solvent.

(vi) Invariant acidic residues

The amino-acids conventionally described as acidic are Asp and Glu. In the case of plastocyanin we may add Cys (which is usually included in the 'polar uncharged' category), since the thiolate group of Cys 84 functions as a Lewis acid by binding the Cu atom. There are then eleven positions in the plastocyanin sequence where an acidic residue is always found: ten Asp/Glu and one Cys (Table 3(f)). Some doubt is still attached to residue 45 which is conserved as Glu, except in poplar plastocyanin where it is reported to be Ser.

In eight of the ten conserved residues with $-COO^-$ groups, the side-chains are directed into the solvent. This is as expected. What is perhaps unexpected is that the acidic residues are significantly more on one side of the molecule than on the other. Six of the conserved Asp/Glu residues, plus Gln 88 (which is also conserved - see above) form a distinctive, elongated, negative patch. We have asked ourselves whether such a distinctive structural feature has a functional significance.

Plastocyanin should have *two* electron-transfer pathways - one to get an electron *in*, and the other to get it *out*. Since two different redox partners are involved in these processes it is unlikely that they make contact with the plastocyanin molecule at the same place. One possible contact point, namely the exposed edge of the His 87 imidazole ring, has already been discussed. The patch of conserved negative residues on the side of the plastocyanin molecule may be another.

This idea was first suggested to us by Dr. Peter Wright. A conserved tyrosine residue, Tyr 83, has its aromatic side-chain in contact with the solvent at about the centre of the negative patch. From that point to the Cu atom there appears to be a straight channel lined by the methylene group of Gly 94, the phenyl rings of Phe 14 and Phe 82, and the aliphatic side-chain of Val 93. Such a channel filled with a medium having a low dielectric constant is a requirement for electron-transfer by "quantum mechanical tunnelling". The existence of a hydrophobic channel does not prove that quantum mechanical tunnelling occurs. It merely satisfied one of the prerequisites.

It may be objected that, since most of the interior of the plastocyanin molecule is filled with hydrophobic side-chains, there are *many* paths through regions of low dielectric constant. What makes the path from the negative patch to the Cu so special is that the four residues which I have mentioned are *invariant*. We note that they include Gly 94 which, unlike the other nine invariant Gly's in plastocyanin, is not found in a bend of the protein chain. The need for a hydrophobic channel from the Cu atom to a negatively charged recognition patch on the surface of the molecule would provide a reason why these four particular residues, including Gly 94, are conserved.

## SUMMARY

The tentative conclusions which we draw from the poplar plastocyanin structure at 2.7Å resolution are as follows: The plastocyanin molecule has evolved to produce a Cu centre which can accept and give up electrons without changes in coordination and with minimal changes in geometry. The Cu centre is not in direct contact with the world outside the protein molecule. There are at least two pathways along which electrons may be transferred to and from the Cu centre by mechanisms which are compatible with the contemporary folk-lore of inorganic electron-transfer reactions. Both these pathways terminate in recognisable patches - at present, the *only* recognisable patches - on the surface of the molecule. (Note 3).

## FUTURE PROSPECTS

A Liversidge Lecture should indicate some directions in which research might proceed from here.

(i) We hope to continue our calculations, incorporating higher resolution data which have already been recorded. This will make the structure analysis more precise. We shall then be able to attach meaningful values to the metal-ligand bond-lengths and bond-angles; we shall be able to study the details of the β-structure (because we shall know just where the hydrogen bonds are); and we shall be able to describe the intermolecular contacts in the crystal, which may lead to an understanding why poplar plastocyanin crystallised so nicely but thirteen other plastocyanins did not.

(ii) If the 'refinement' calculations in (i) lead to a sufficiently precise knowledge of the structure, then it will probably be possible to detect how the protein responds structurally to various chemical changes. For example, we already know that Cu(I)-plastocyanin is isomorphous with Cu(II)-plastocyanin. The measurement of X-ray diffraction data for Cu(I)-plastocyanin to high resolution should therefore enable us to calculate the changes in electron-density (i.e. changes in structure or conformation) which accompany electron-transfer. Similarly it may be possible to determine whether the protein conformation is affected by pH; and it may be possible to locate the binding sites of certain inorganic redox reagents which are known to associate strongly with the protein before electron transfer takes place.

(iii) It would be interesting to study the structure of stellacyanin, a glycoprotein with a 'Type 1' Cu centre. This protein lacks Met residues completely so that at least one of the ligand groups at the Cu centre cannot be the same as in plastocyanin. We have not yet succeeded in crystallising stellacyanin, but we do have crystals of a new basic green-blue protein from cucumber seedlings (Colman *et. al.*, 1977*b*). Both stellacyanin and the cucumber protein have spectroscopic properties which are significantly different from those of plastocyanin. An understanding of the structural reasons for the spectroscopic differences between plastocyanin, stellacyanin and the basic cucumber protein may help to improve the predictive values of the various spectroscopic techniques when applied to metalloproteins.

(iv) In the long term it will be necessary for someone to study the structures of Cu-proteins with 'Type 2' and 'Type 3' Cu centres. The enzyme laccase is particularly attractive from this point of view since it contains a 'Type 1' centre, a 'Type 2' centre and a (double Cu) 'Type 3' centre. At this time no one has been able to induce laccase to crystallise in a form which diffracts X-rays.

It is a chastening epilogue to this lecture that the nucleation of crystals - a chance event which we cannot yet understand, predict or control - still stands between us and the investigation of Nature's molecular designs.

## ACKNOWLEDGEMENTS

I am pleased and grateful that this Liversidge Lecture gives me the opportunity to acknowledge the contributions and assistance of many colleagues.

First and foremost I thank those who have worked on the plastocyanin project; *Donald* (now *Dr. D.J.*) *Fensom* (Honours student, 1971), who isolated our first specimen of French bean plastocyanin and later - as a Ph.D. student - recorded high-field n.m.r. spectra at Oxford and kinetic data at the California Institute of Technology; *Tad Bohdanowicz* (Research Assistant, 1972); *Elizabeth* (now *Dr. E.J.*) *Woodcock* (Research Assistant, 1973); *Dr. Graeme Chapman* (Professional Officer, 1974-5), who set up our protein chemistry laboratory in its present form; *Dr. John Ramshaw* (Research Fellow and Professional Officer, August 1974 - February 1977), who brought to the research a superb feeling for Cu-protein biochemistry, and maintained a passion for purifying plastocyanin from all sorts of leaves until poplar plastocyanin finally yielded crystals; *Dr. M.P. Venkatappa* (Research Fellow, 1975-7), whose patience and attention to detail were essential for the long series of systematic crystallisation experiments and the production of isomorphous heavy-atom derivatives; *Alan Watson* (Research Assistant, 1975); *Dr. Peter Colman* (Queen Elizabeth II Fellow and later N.H. & M.R.C. Research Fellow, 1975-8), a distinguished protein crystallographer working on his own project in our laboratory, who gave us a great deal of his know-how and active collaboration; *Dr. Mitchell Guss* (Professional Officer, 1975 --), who deserves most of the credit for the structure analysis; *Valerie Norris* (Research Assistant (1976 --); and *Dr. Mitsuo*

*Murata* (Professional Officer, 1976--). The three last-named colleagues are still continuing the work.

*Dr. James K. Beattie, Dr. Peter Wright* and *Dr. Carolyn Wright-Mountford* are departmental colleagues who were particularly helpful when we came to evaluate and interpret our results. *Dr. Julian Wells* at the University of Adelaide, who isolated and characterised French bean plastocyanin in 1971, gave us helpful telephoned advice during our early protein isolation experiments. *Dr. Bill O'Sullivan* (now *Professor W.J. O'Sullivan* of the School of Biological Sciences at the University of New South Wales) was the person who first pushed Milne and Wells' plastocyanin paper under my nose. *Mr. J. Sumeghy* at the Hawkesbury Agricultural College showed us how to grow French beans in 1971 and 1972. *Dr. Frank Crofts*, Director of the Sydney University Research Farms at Camden, made fields, advice and labour available for the production of crops of numerous vegetables from 1973 to 1976. Experimental facilities at the C.S.I.R.O. Division of Food Research, North Ryde, were made available through the courtesy of *Mr. M.V. Tracey*, Chief of the Division, in 1971-2 when we had not yet established our own protein laboratory. For some years beginning in 1971 we also benefited from having *Mr. Malcolm Smith* at the C.S.I.R.O. Division of Food Research to hold our inexperienced inorganic hands while we extracted and purified our protein specimens.

Much of our laboratory's folk-lore concerning protein crystallisation dates back to a very useful one-month visit by *Mr. Larry Sieker* in 1975. For the purpose of that visit he was helpfully released from his normal duties in *Professor Lyle Jensen*'s laboratory at the University of Washington, Seattle. *Professor Jan Drenth* at Groningen and *Professor Robert Huber* at Munich supplied us with computer programs which were subsequently adapted to our needs and computer configuration and used in the structure analysis. *Dr. Richard Ambler* at Edinburgh determined the amino-acid sequence of poplar plastocyanin. Two of my friends in the Cu-protein business, *Dr. Allen Hill* at Oxford and *Professor Harry Gray* at the California Institute of Technology, provided challenge, stimulation and encouragement over a long period.

An unforgettable example of fraternal generosity was provided by *Professor Hans Jansonius* at the Biozentrum in Basel, Switzerland. I was visiting Basel in 1976 when Mitchell Guss cabled me that poplar plastocyanin had been successfully crystallized at last. Due to an ambiguity in the cable I thought that we had only ten crystals and that the next Australian poplar season was a year away. Basel, however, was full of leafy poplar trees. Although Professor Jansonius was busy preparing an important lecture for an international meeting, he immediately mobilised his research group, obtained the official blessing of the Canton of Basel, and stripped the cantonal poplars of their leaves. In the end we did not take advantage of this supply of raw material: the apparent lack of poplar leaves in Sydney was shown to be the result of a misunderstanding, and the Basel poplars turned out to belong to a different species than those in Sydney.

Finally, it is a pleasure to record that the study of the crystal structures of metalloproteins at Sydney University has been supported by the Australian Research Grants Committee, by the University of Sydney through the University Research Grant and a General Development Grant, and in 1978 by a donation from Esso Ltd.

NOTES

Note 1.

The diffraction process is governed by the Bragg equation, $n\lambda=2d\sin\Theta$. The larger the angles $\Theta$ at which reflections can be recorded, the smaller are the spacings $d$ which can be resolved.

Note 2.

X-ray data sets were recorded for the native protein and for three heavy-atom derivatives which were isomorphous with the protein. The derivatives were obtained by soaking protein crystals in solutions of mercuric acetate, uranyl acetate for 23 h, and uranyl nitrate for 10 d, respectively. The X-ray data were initally recorded to a resolution of 2.7Å. The measurements for the derivatives included anomalous dispersion data. The crystals were extremely stable so that a single crystal lasted for the entire week which was required for each set of X-ray measurements. Standard computational techniques were used to calculate an electron-density map. A model was then fitted to the electron-density in a Richards optical comparator, using scaled model-building components.

Note 3. (added in March, 1979)

Subsequent refinement of the structure at 1.6Å resolution has produced more precise values for the positions of the protein backbone and side-chains, and has cast doubt on the description of a hydrophobic channel from Tyr 83 to the Cu atom.

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# A Reappraisal of the Late Devonian Bective Unconformity

T. G. Russell

ABSTRACT. Re-investigation of the Bective Unconformity beneath the Late Devonian Keepit Conglomerate reveals that there is insufficient conclusive evidence for the designation of this unconformity as a significant angular discordance of regional extent.

The basal contact of the Keepit Conglomerate varies from, in the west of the Tamworth Belt (the basin edge), a disconformable contact between predominantly terrestrial and underlying marine sediments, passing eastwards (basinwards) to initially an abrupt, often disconformable contact beneath coarse redeposited sediments, thence to a gradational and conformable contact with the underlying mudstones. It is concluded that the Bective Unconformity is a basin edge disconformity, which passes basinwards to a disconformable contact beneath coarse resedimented deposits. The duration of the hiatus at the basin margin lies entirely within the Famennian. Further towards the basin depocentre the unconformity is nonexistent.

INTRODUCTION

The Tamworth Belt (Harrington, 1974; Korsch, 1977) is an arcuate zone of mildly deformed strata ranging in age from Cambrian (Cawood, 1976) to Permian (Packham, 1969), situated to the west of the more complexly deformed Central Complex (Harrington, 1974). The Tamworth Belt and Central Complex together constitute the southern part of the New England Fold Belt (Leitch, 1974). The Tamworth Belt contains a dominantly terrigenous sequence of predominantly Devonian and Carboniferous age within which a number of unconformities have been recognised. The Bective Unconformity is a Late Devonian hiatus which separates the Late Devonian Keepit Conglomerate from underlying Late or Middle Devonian strata (Table 1).

It is the intention of this paper to review the status of the Bective Unconformity, and to present new data on the nature of the basal contact of the Keepit Conglomerate deriving from a regional study of this unit (Russell, 1977).

THE BECTIVE UNCONFORMITY

The Bective Unconformity was formally defined by White (1964c) as an angular unconformity between the Baldwin Formation and the overlying Keepit Conglomerate. Its existence was first postulated from the Somerton-Attunga area, with subsequent extension to other parts of the Tamworth Belt largely through the regional studies of Leslie (1963), McKelvey and White (1964) and White (1964a, b, c; 1965, 1966). An unconformity recognised at the base of the Keepit Conglomerate in the Timor Valley, the Isis Unconformity of Manser (1968), has been equated with the Bective Unconformity (Manser, 1968; Ellenor, 1971).

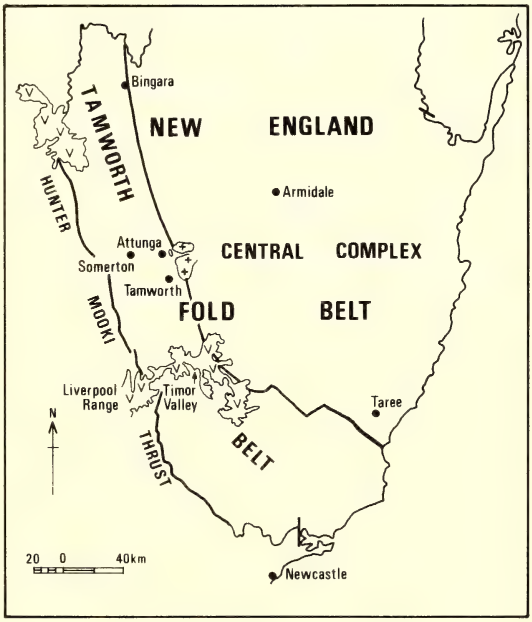


Fig. 1 Location of the Tamworth Belt

Evidence for the Unconformity

The existence of the Bective Unconformity was based by various workers on the following evidence:

1. White (1964a, c) considered the structural trends of the Baldwin Formation to differ markedly in places to the trends

Discussion

Lithology

Probably the most noticeable feature of the Bective Unconformity is the sudden change in lithology from mudstone to coarse conglomerate (McKelvey, 1966; Manser, 1968), upon which the existence of the unconformity is often unwisely based. This, however, need not indicate an unconformable relationship or significant time lapse, as pointed out by McKelvey (1966). The rapid and drastic change in the grade of sediment being deposited simply reflects a marked coarsening of the sediment being supplied to the depositional basin, and results from tectonic activity within the source area (Russell, 1977, and *in prep.*) rather than indicating a period of deformation of the depositional basin and its fill.

Angular Discordance

Evidence relating to the angular discordance is dubious. Of the grid references to the unconformable contact given by White (1964c) one plots upon his map entirely within the Baldwin Formation (map ref. 106E, 250N) while another upon field inspection can be seen to be a fault (map ref. 153E, 169N) (Map references are quoted from White 1964c, p.211). This latter situation appears to be the cited instance of "an angular discordance that may be as great as $90^{\circ}$" (White, 1964a). However, in this outcrop shallow dipping Keepit Conglomerate can be seen to be in fault contact with vertical Baldwin Formation. The exposure of the supposed angular discordance cited by Leslie (1963), a road cut on the Oxley Highway, was re-examined. No trace could be found of the Keepit Conglomerate and hence the nature of any contact was indeterminate. One can only infer the quality of the exposure of any unconformity has deteriorated or subsequent roadwork has obliterated the contact. Close examination of the locality cited in McKelvey and White (1964) shows the stratification of the underlying thin bedded and laminated sequence of mudstones and sandstones to be parallel to the overlying Keepit Conglomerate sandstones. Some basal scouring was observed, but no angular discordance was found. The angular discordance reported by Osborne et al. (1948) has not been substantiated either by later workers or by myself. I therefore consider there is insufficient evidence for the existence of a strong angular unconformity beneath the Keepit Conglomerate.

Cross Folding

Cross folding is developed not only in the Baldwin Formation but also in the Keepit Conglomerate, although occurring in the latter as large scale basins and domes (White, 1964c). However, smaller scale cross folding as that in the Baldwin Formation, is more likely to be detected in outcrops of the argillites of this unit than in the poorer quality outcrops of massive conglomerates and sandstones of the Keepit Conglomerate. As both the Baldwin Formation and Keepit Conglomerate are cross folded I consider that the presence of cross folding is not conclusive evidence for the deformation of the Baldwin Formation prior to deposition of the Keepit Conglomerate, nor for the existence of the Bective Unconformity.

Stratigraphy

That the Keepit Conglomerate overlies the Eungai Mudstone, the Lowana Formation and the Baldwin Formation in different parts of the Tamworth Belt is of little value as evidence for a regional unconformity. No evidence exists for the upper horizons of the Baldwin Formation in the Somerton-Attunga area being of different age to the Eungai Mudstone in the northern part of the belt. The Eungai Mudstone together with the underlying Lowana Formation and Noumea Beds are correlated with the Baldwin Formation (McKelvey and White, 1964; McKelvey, 1974). The occurrence of the Keepit Conglomerate overlying both the Eungai Mudstone and the Baldwin Formation simply reflects the differing stratigraphic nomenclature used in different parts of the Tamworth Belt (Table 1).

The Keepit Conglomerate is mapped at two localities by McKelvey and White (1964) and White (1965) as overlying the Lowana Formation rather than the Eungai Mudstone. Given the quality of outcrop in these two areas, I could find no evidence to prove or disprove their interpretation. It is conceivable that locally submarine erosion has cut through the Eungai Mudstone. However, it is equally possible that facies variation within the Eungai Mudstone has resulted in sandier "Lowana-like" Eungai Mudstone does become both thinner and sandier from east to west (McKelvey, 1966; White, 1966). Hill (1973), mapping in this area, chose not to differentiate the Eungai and Lowana due to their similarities and treated tham as one informal unit. Whichever interpretation is correct, a regional unconformity is not indicated.

The Bective Unconformity in the Timor Valley

The change in sedimentation type, as discussed above, is considered unreliable evidence for the existence of the Bective Unconformity, while the greater degree of induration and quartz veining probably reflects in part the typically more siliceous, cherty nature of this part of the sequence (Crook, 1959a; Manser, 1968). To date, no unequivocal exposure has been reported of the Bective Unconformity in the Timor Valley. Furthermore, this unconformity which separates Late Devonian from Middle Devonian strata has been placed at different horizons within the sequence, as shown by a study of the maps of Osborne et al. (1948) and Manser (1968). Strata included beneath the unconformity by Osborne et al. are placed above the unconformity by Manser. Manser's comments on the similarity of the deformation style above and below the unconformity would seem to argu against any markedly different deformational histories which could be expected in view of the proposed nature and duration of the unconformity.

Perhaps the most convincing evidence presented for the existence of the Bective Unconformity in the Timor Valley, and also for its being here a major erosional feature of some duration, is the apparent absence of the Baldwin Formation and part of the Yarrimie Formation (Manser, 1968) and the

of the overlying sediments. He noted cross folding in the Baldwin Formation, and assumed deformation of this unit occurred prior to deposition of the overlying sediments.

2. Angular discordance between the Keepit Conglomerate and the underlying formations (Osborne et al., 1948; Leslie, 1963; McKelvey and White, 1964; White, 1964a, c).

3. In different areas of the Tamworth Belt the Keepit Conglomerate overlies the Eungai Mudstone, the Lowana Formation, the Baldwin Formation and the Yarrimie Formation (McKelvey and White, 1964; White, 1965, 1966; McKelvey, 1966; Manser, 1968; Ellenor, 1971). This has been taken to indicate pronounced erosion on a regional scale.

4. In the north of the Tamworth Belt no structural discordance has been recognized and the Bective Unconformity was considered to be a disconformity marked by a sudden prominent lithological change with an erosional contact present in some localities (McKelvey, 1966).

5. In the Timor Valley the Bective Unconformity (Isis Unconformity of Manser, 1968) separates the Keepit Conglomerate from the underlying Middle Devonian Yarrimie Formation. An unconformity between the Middle and Upper Devonian within the Timor Valley was first suggested on the basis of scant data by Osborne et al. (1948). The Isis Unconformity, separating Late Devonian strata from the underlying Middle Devonian Yarrimie Formation, was named by Manser (1968) and correlated with the Bective Unconformity of White (1964c) occurring further north. Manser (1968) gave the greater degree of induration and quartz veining of the Middle Devonian sediments (criteria of Osborne et al., 1948) and the change in sedimentation type as evidence for the Isis Unconformity, adding that "there is only a slight structural break across the unconformity ... but the style of deformation does not appear to differ" (Manser, 1968). Manser considered erosion associated with the unconformity removed local equivalents of the Baldwin Formation and cut in to the Yarrimie Formation. Ellenor (1971) assumed, on the basis of palaeontological data, the upper horizon of the Timor Limestone to be a time plane to demonstrate the existence of an erosion surface with relief in the order of 200 metres (the Bective Unconformity) cut into the Yarrimie Formation. He considered the Keepit Conglomerate to be deposited upon this surface.

The Bective Unconformity has thus been considered to be a significant Late Devonian hiatus of regional extent (Leslie, 1963; White, 1966), but of variable nature (McKelvey, 1966) throughout the Tamworth Belt. Crook (1959a, 1961), however, in his study of the area from Tamworth to the Timor Valley, did not record an unconformity at the stratigraphic level of the Bective Unconformity. The Bective Unconformity is considered to be of appreciable duration by White (1964c) and Ellenor (1971), although McKelvey (1966), points out the disconformity in the far north of the Tamworth Belt may represent only a short time gap, its recognition being due to the marked contrast in lithologies.

Subaerial erosion is considered to have occurred by Ellenor (1971) for the Timor region, while White (1964c) and McKelvey (1966) invoke submarine erosion. The concept of submarine unconformities has been discussed by Crook (1959b) who stressed that such unconformities need not imply either subaerial erosion or tectonic upheavals.

TABLE 1
THE STRATIGRAPHIC POSITION OF THE KEEPIT CONGLOMERATE AND BECTIVE UNCONFORMITY

| | A | B | C |
|---|---|---|---|
| Late Devonian | Mandowa Mudstone<br>Keepit Conglomerate | Mandowa Mudstone<br>Keepit Conglomerate | Mandowa Mudstone<br>Keepit Conglomerate |
| | —— | Bective Unconformity | —— |
| | Eungai Mudstone<br>Lowana Formation<br>Noumea Beds | Baldwin Formation | |
| Middle Devonian | | | Yarrimie Formation |

A Northern part of Tamworth Belt (McKelvey and White, 1964)
B Somerton-Attunga area (White, 1964c)
C Timor Valley (Manser, 1968; Ellenor, 1971)

erosional surface cut into the Yarrimie Formation, as described by Ellenor (1971).

This erosional surface is based on a diagram (Ellenor, 1971, Fig. 11.4) showing the thickness of sediment between the top of the Timor Limestone, assumed to be a time plane on the basis of conodont zonation, and the base of the Keepit Conglomerate. The distance covered by this diagram is an area on the western limb of the Timor Anticline where the Keepit Conglomerate is thin, intermittently exposed from beneath Tertiary basalts, and lacking a readily recognisable basal contact, unconformable or not, with the underlying sediments. Ellenor has joined a limited number of points to define a channel-like erosional surface. For much of the distance covered by the diagram, including all of the channel's southern slope, the Keepit Conglomerate is exposed, no evidence of erosional contacts can be found. In fact, the Keepit Conglomerate lacks a well defined basal contact in this area and appears to be both conformable and gradational with the underlying strata. The Keepit Conglomerate is shown in Ellenor's diagram as thinning into and up the northern flank of the erosional channel. This thinning, atypical of coarse, channel fill deposits, is considered further evidence against the erosional surface as suggested by Ellenor (1971).

An alternative to this erosion surface is the occurrence in this area of the Keepit Conglomerate as a number of discontinuous lenses of coarse sediment at several different stratigraphic levels within a sequence of predominantly mudstone. This is supported by the presence of conformable basal contacts, and the observation by Ellenor (1971, p. 42) that in this area the Keepit Conglomerate "is discontinuous, and only restricted conglomerate lenses (9m thick) are developed".

If this interpretation is correct, the Baldwin Formation, present some 8 km to the north on the other side of the Liverpool Range (Crook, 1959a; Offenber, 1971), could exist in the Timor Valley but only as a thin mudstone dominant sequence occurring conformably between the Yarrimie Formation and the Keepit Conglomerate. Alternatively, the Baldwin Formation may never have been deposited in this region, and time equivalent strata would be present in the upper horixons of the Yarrimie Formation and/or the lower portion of the Keepit Conglomerate. Palaeontological data which might provide support for either of these two possiblities are currently unavailable.

Both conformable and disconformable contacts occur between the Keepit Conglomerate and the underlying strata in and to the south of the Timor Valley (Deroubaix, 1977; Russell, 1977). The disconformable contacts occur beneath coarse redeposited sediments while the conformable contacts occur where the Keepit Conglomerate is of finer grade.

Summary

It is considered that the evidence for the existence of the Bective Unconformity as an extensive unconformity of often marked angular discordance, implying "major tectonic disturbance as well as considerable erosion" (White, 1966, p. 222) is unreliable.

Within the Timor Valley the situation is less obvious. The presence of both conformable and disconformable contact, together with doubtful value of the evidence of Manser (1968) and Ellenor (1971) argues against the existence here of the unconformity as conceived by these authors. The occurrence of the Bective Unconformity in the Timor Valley as an unconformity of significant duration rests upon the absence of the Baldwin Formation. From the discussion above, evidence for the absence of this unit due to erosion is not convincing. I consider the Bective Unconformity within the Timor Valley to be a locally developed disconformable contact of unknown relief occurring between coarse redeposited sediments of the Keepit Conglomerate and the underlying strata. No evidence exists for a period of subaerial erosion having occurred.

Fig. 2. Conformable and gradational contact of Keepit Conglomerate and Eungai Mudstone. The Eungai Mudstone contains thin medium bedded Keepit Conglomerate-type sandstones which rapidly become thicker and closer spaced at the expense of the mudstone. GR34342950 Inverell 1:250 000 Sheet SH56-5.

THE BASAL CONTACT OF THE KEEPIT CONGLOMERATE

Of the measured sections of the Keepit Conglomerate (Russell, 1977) 46% (19 sections) have exposed a basal contact with the underlying unit. Two types of non faulted basal contacts may

be recognized:

1. Conformable and gradational.
2. Disconformable and/or marked by an abrupt lithological change.

In the first case the underlying Eungai Mudstone passes up to the Keepit Conglomerate by an increase in the number and thickness of sandstone beds. The basal contact of the formation is taken at the base of the first thick sandstone bed. In this instance the contact is clearly conformable (Fig 2).

In the second case coarse sandstone or conglomerate of the Keepit Conglomerate sits sbruptly upon mudstones of the underlying units. Depending on the nature of the outcrop, an erosional contact may be recognized. The scale of erosion in outcrop is usually in the order of a few metres. No significant attitude difference exists between the Keepit Conglomerate and the underlying sediments, although it is often difficult to obtain reliable dips in the conglomerate.

Two aspects of the disconformable contact may be recognised. In the first, predomantly terrestrial sediments (Russell, 1977, and *in prep.*) disconformably overlie marine sediments in the Lake Keepit area (Fig. 3). The duration of time represented by this hiatus can be said to lie within the Famennian. Famennian fossils have been recorded from the Baldwin Formation beneath the Keepit Conglomerate (Pickett, 1960; Jenkins, 1966) and from the Mandowa Mudstone above the Keepit Conglomerate (Pickett, 1960; Jenkins, 1968). No evidence exists as to the geographical extent of probable subaerial erosion.

Fig. 3. Disconformable contact between terrestrial coarse conglomerage of the Keepit Conglomerate and marine mudstones of the Baldwin Formation. GR34441826 Manilla 1:250 000 Sheet SH56-5.

In the second situation the disconformity takes the form of submarine erosion or scouring at the base of redeposited sediments (Fig. 4, 5), as orginally conceived by White (1964c) and McKelvey (1966). The scale of erosion in outcrop is usually in the order of a few metres, but deeper larger channelling may be present as indicated by the presence in some sections of large mudstone blocks considered to be derived from channel walls, and the occurrence within the Keepit Conglomerate of channels in the order of 10 metres deep (Russell, 1977).

Fig. 4. Disconformable contact between marine conglomerate of the Keepit Conglomerate and marine mudstones of the Eungai Mudstone. GR33652740 Manilla 1:250 000 Sheet Sh56-9.

Fig. 5. Disconformable contact between marine coarse sandstones of the Keepit Conglomerate and marine finer sediments of the Baldwin Formation. GR 36841773 Manilla 1:250 000 Sheet SH56-9.

Sections illustrating the second type of disconformable contact usually lie to the east of those possessing a conformable contact. The basal contact of the Keepit Conglomerate thus varies from a disconformable contact between terrestrial and marine sediments near the basin margin to initially an abrupt, usually disconformable contact beneath coarse redeposited marine sediments thence to a conformable and gradational contact in a more basinwards location.

CONCLUSIONS

I consider the Bective Unconformity to be a basin disconformity which passes basinwards (eastwards) to an erosional contact beneath redeposited strata. As such it differs to the original concept of an angular unconformity (White, 1964a) based largely on equivolcal criteria. No reliable evidence exists for major tectonic disturbances affecting the depositional basin prior to deposition of the Keepit Conglomerate.

The extent of subaerial erosion appears to have been local, limited to the western margin of the Tamworth Belt (the basin edge). The amount of subaerial erosion is unknown. The precise duration of the hiatus is not easily determined but lies within the Famennian. The disconformity need have no temporal significance when resulting from erosion beneath redeposited sediments. The scale of erosion in these latter instances may be in the order of ten metres or more.

Towards the basin depocentre the Bective Unconformity is absent and the Keepit Conglomerate is conformable upon the underlying strata.

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# Stratigraphic Palynology of the Mooki Valley, New South Wales

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ABSTRACT. The palynology of over twenty bores in the Mooki Valley are reported. The bedrock contains either (1), Stage 5 (or the *Dulhuntyispora* assemblage) which is Upper Permian and equivalent to the 'Upper Coal Measures' or (2), the *Protohaploxypinus reticulatus* assemblage, which is equivalent to the basal lithologic units of the Narrabeen Group. The Cainozoic valley fills contain either Pliocene or Pleistocene assemblages with the exception of one anomolous sample which may be late Miocene.

In two, possibly three bores, the Pliocene sediments directly overlie bedrock. This suggests that deposition did not start until the Pliocene and that Tertiary uplift along the Mooki Thrust System may be a late Miocene-Pliocene event.

The pollen assemblages and abundance of predominantly brown clays suggests a dry type of closed forest and a climate with a marked seasonal drought.

## INTRODUCTION

The Water Resources Commission of New South Wales has sunk many bores in the alluvium of the Mooki River Valley in its programme of exploration for underground water. This paper presents the results of the palynological study of the Mooki Valley. Of thirty bores examined, approximately twenty yielded workable assemblages of spores and pollen. Several bores just north of the Namoi River have been included as they are in close proximity to the Mooki Valley.

In Mooki Valley which is located in the Sydney-Bowen Basin, the useful undergound water is found in the Tertiary valley fills. One of the problems of drilling in this area is the detection of bedrock which is highly weathered and friably hence shows little difference to the overlying unconsolidated sediments. Since most bores have penetrated the Permian bedrock its palynology is included here.

## GEOLOGY

The Mooki Valley is located in the Gunnedah Basin which is one of the sub units of the Sydney-Bowen Basin. Outcrops of Permian and Triassic rocks are widespread throughout the Sydney-Bowen Basin. In the area of this study, the "Lower Coal Measures" (Lower Permian), marine Permian, and, "Upper Coal Measures" (Upper Permian) and the equivalents of the Narrabeen Group (Late Permian and Triassic) are found. Fig. 1 shows these outcrops. The valleys are filled with Tertiary-Recent alluvium (Menzies, 1975; Branagan, 1969).

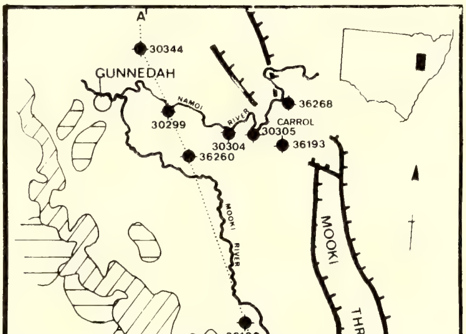


Fig. 1. Location of bores and the major geological features of the Mooki Valley.

The upper part of the bores penetrate the unconsolidated alluvium. The bore logs show clays and gravels. Some bores are almost entirely clay, some mostly gravel, whereas others show alternate banding of clays and gravel. Sand and silt are present as minor components. The colours are predominantly brown, yellow brown, khaki and orange brown, occasionally reddish and whitish. Grey clays and carbonaceous clays are unusual but they have been encountered in several bores. This upper part extends down to bedrock which may be weathered conglomerate, sandstone or shale. Frequently the bedrock is almost indistinguishable from the overlying unconsolidated sediments. Coal, carbonaceous material and grey clays are commonly encountered in the bedrock. Selected logs are shown in Fig. 3.

Only the grey clays, carbonaceous clays and coal were found to be suitable for palynology. Pollen has not been recovered any of the brown, yellow, orange or red clays unless thin bands of grey or carbonaceous clays are present. It is thought that the brown (etc.) clays indicate that the conditions of deposition were too oxidising for pollen preservation.

This study area is just west of the Mooki Thrust System which is part of the border thrusts of the New England Plateau. Movement occurred along this thrust System in the Permian, and possibly earlier. It is thought that the elevated region east of the Mooki Thrust System controlled the deposition of coal in the Gunnedah Basin (Brownlow, 1978). There were a number of upward movements following the outpouring of basalts during Oligocene time (Voisey, 1969).

## PALYNOSTRATIGRAPHY

### Permian

Balme (1964) described the *Dulhuntyispora* assemblage of the Upper Permian. A major microfloral break was interposed between Upper Permian and Triassic assemblages. Helby (1973) described the *Protohaploxypinus reticulatus* assemblage from the basal lithologic units of the Narrabeen Group which he placed in the Upper Permian, between the older *Dulhuntyispora* assemblage and the Triassic. Several other workers have constructed stratigraphic schemes, and of these Stage 5 with a number of sub-units, is equivalent to the *Dulhuntyispora* assemblage. All of these schemes are reviewed by Kemp *et al.*, (1977) who proposes an additional unit, the *Weylandites* Zone which occurs between Stage 5 and the *P. reticulatus* assemblage.

With the exception of two samples, the assemblages contain an abundance of bisaccate pollen of both the striatid and non-striatid types. Poor preservation in some of the samples has limited specific identification and the diversity of bisaccates is probably greater than that indicated by the list in Table 1. A few monosaccates are present, but not nearly as abundant as the bisaccates. Spores are common and generally better preserved than the bisaccate pollen. The distinctive *Didecitriletes ericanus* is found in practically every sample. The palynomorphs and their occurrance are listed in Table 1, and the zone or stage of each sample is shown in Fig. 3. *Dulhuntyispora parvitholus*, found in some of the samples restricts the assemblages to Upper Stage 5. Those that do not contain *D. parvitholus* do not differ in their overall characteristics so this species absence may be a chance ommission. The presence of *Polypodiidites cicatricosus* and *Dulhuntyispora dulhuntyi* f. 296 restrict Bores 36124 and 36131 to the Upper Stage 5a.

The assemblages found in Bores 30141 and 30061 are poorly preserved and there is low diversity. Bisaccates are present but not as abundant and *Osmundacidites* is common. These characteristics and the presence of *Nevesisporites fossalatus* indicates the *P. reticulatus* assemblage. No palynomorphs which first appear in the Triassic are found. These assemblages are listed in Table 1 also.

### Cainozoic

Tertiary spore pollen zonation for the Gippsland Basin, of south eastern Australia has been described by Stover and Partridge (1973). This scheme extends to about the end of the Miocene. Several Pliocene assemblages have been described from western Victoria (Harris, 1971) and Queensland (Hekel, 1972). Both Pliocene and Pleistocene occur in south western New South Wales (Martin, 1973, 1969). The relevant parts of the latter stratigraphic scheme is shown in Fig. 2, in Martin (1977).

The *Triporopollenites bellus* Zone (Stover and Partridge, 1973) contains an abundance of *Nothofagus* in the lower part of the zone but it becomes less common in the upper part. Of the characteristic zone species only *Haloragis haloragoroides* is applicable to this study. It first appears in the upper part of the zone, which is late Miocene, possibly extending into the Pliocene.

Several 'phases' have been described from the Pliocene. There are two Myrtaceae-*Casuarina* phases, one older, one younger and their main palynological characteristics are almost identical. The *Nothofagus* phase is found above the older Myrtaceae-*Casuarina* phase. In western New South Wales, only the *menziesii* and *fusca* pollen types of *Nothofagus* occur in the *Nothofagus* phase, and the *brassii* type which is common in the Miocene, is absent. A number of other pollen types associated with *Nothofagus* in the Miocene also reappear with it in the Pliocene. The *Nothofagus* phase is followed by the Gymnosperm phase, in which gymnosperms become more abundant, which is then followed by a return to the younger Myrtaceae-*Casuarina* phase. The *Nothofagus* and gymnosperm phases are thought to be Upper Pliocene. It is not known whether the older Myrtaceae-*Casuarina* extends back to the beginning of the Pliocene.

It appears that the Pliocene can be distinguished from the Pleistocene on the basis of the abundance of the "herbaceous group", as shown in Table 2. Three main pollen types constitute the herbaceous group, viz. the chenopod-type, Compositae and Gramineae. Each herbaceous pollen-type is more abundant in the Pleistocene than the Pliocene, although there is some overlap.

TABLE 1

DISTRIBUTION OF PERMIAN PALYNOMORPHS (BORES ARRANGED IN ORDER, N → S and W → E)

| PALYNOMORPH | Bore & depth (m) | 36190 88.7 - 90.8 | 36124 64.0 - 73.1 | 36131 83.8 - 89.9 | 36129 74.7 - 86.9 | 36123* 114.6-115.8 | 30379 110.3-112.8 | 30381 86.7 - 88.4 | 30271 70.1 | 30063 74.6 - 138.0 | 30141* 35.0 - 38.0 | 30061* 97.1 - 99.1 | 30182 38.1 - 45.7 | 30183 30.5 - 48.8 | 30142 39.6 - 59.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acanthotriletes dentatus* Balme & Hennelly, 1956 | | | + | | | | + | | + | + | | | | | |
| *A. tereteangulatus* Balme & Hennelly, 1956 | | | | | | | | | | + | | | | | |
| *A. uncinatus* Balme & Hennelly, 1956 | | | | + | + | | | | | | | | + | | |
| *Apiculatisporites filiformis* Balme & Hennelly, 1956 | | + | | | | | | | | + | | | + | | + |
| *Bacanisporites undosus* Balme & Hennelly, 1956 | | | + | | | | | | | | | | | | |
| *Calamospora diversiformis* Balme & Hennelly, 1956 | | | | | | | | | | + | | | | | |
| *Dentatispora* sp. | | | | | + | | | | | | | | | | |
| *Didecitriletes ericanus* (Balme & Hennelly) Venkatachala & Kar, 1965 | | + | + | + | + | | + | + | + | + | + | | + | + | + |
| *Dulhuntyispora dulhuntyi* Potonié, 1956, forma 296 of Price (unpubl.) | | | | + | | | | | | | | | | | |
| *D. dulhuntyi* Potonié, 1956, forma 297 of Price (unpubl.) | | | | | | | | | | + | | | | | |
| *Dulhuntyispora parvithola* (Balme & Hennely) Hart, 1965 | | | | | | | + | | | + | | | + | | + |
| *Granulatisporites micronodosus* Balme & Hennelly, 1956 | | + | + | + | + | | + | | | + | | | | | |
| *G. trisinus* Balme & Hennelly, 1956 | | + | + | + | + | + | + | + | + | + | | | | + | + |
| *Gondisporites* sp. | | | | | + | | | | | | | | + | | |
| *Kraeuselisporites rallus* Balme, 1970 | | | | | | | + | | | | | | | + | |
| *Kraeuselisporites* cf. *K. wargalensis* Balme, 1970 | | | | | | | | | | | | | | + | |
| *Leiotriletes directus* Balme & Hennelly, 1956 | | + | | | + | | | | | + | | | + | | + |
| *Marsupipollenites triradiatus* Balme & Hennelly, 1956 | | | | | | | | | | | | | + | | |
| *Microbaculispora villosa* (Balme & Hennelly) Bharadwaj, 1962 | | | | + | + | | + | + | | + | | | + | | |
| *Nevesisporites fossulatus* Balme, 1970 | | | | | | | | | | | + | | | | |
| *Nuskoisporites* sp. | | | | + | | | | + | + | + | | | + | | + |
| *Osmundacidites* sp. | | | | | | | | | | | + | + | | | + |
| *Peltacystia venosa* Balme & Segroves, 1966 | | | | | | | + | | | | | | | | |
| *Polypodiidites cicatricosus* (Balme & Hennelly) Rigby & Hekel, 1977 | | | + | + | | | | | | | | | | | |
| *P. mutabilis* Balme, 1970 | | | | | | | | | | | | + | | | |
| *Praecolpatites sinuosus* (Balme & Hennelly) Bharadwaj & Srivastava, 1969 | | | | | | | + | | | | | | | | |
| *Protohaploxypinus limpidus* (Balme & Hennelly) Balme, 1970 | | | + | + | | | | + | | + | | | + | + | + |
| *P. reticulatus* (Hennelly) Helby, 1973 | | | | | | | + | | | | | | + | + | + |
| *Protosacculina multistriata* (Balme & Hennelly) Balme, 1964 | | | + | | | | | | | | | | | | |
| *Striatopodocarpidites cancellatus* (Balme & Hennelly) Balme, 1970 | | | + | + | | | + | + | + | + | | | + | + | + |
| *S. fusus* (Balme & Hennelly) Potonié, 1958 | | | | | | | | | | | | | + | | + |
| *Sulcatisporites ovatus* (Balme & Hennelly) Balme, 1970 | | | | | | | | | | | | | | + | + |
| *Tiwariasporis* cf. *Marsupipollenites scutatus* Balme & Hennelly, 1956 | | | + | + | | | | + | + | | | | | | + |
| *Verrucosisporites bullatus* Balme & Hennelly, 1956 | | | | | | | | | | + | | | + | | |
| *V. psuedoreticulatus* Balme & Hennelly, 1956 | | | | | + | | | | | | | | | | |
| *V. trisectatus* Balme & Hennelly, 1956 | | | | | | | | | | | | | + | | |
| *Vitreisporites pallidus* (Reissinger) Balme, 1970 | | | | | | | + | | | | | | | | + |
| *Weylandites lucifer* (Bharadwaj & Salujha) Foster, 1975 | | | | | | | | | | + | | | | | |

* The poor preservation makes specific identification of the bisaccates uncertain.

TABLE 2
HERBACEOUS POLLEN TYPES IN PLIOCENE AND PLEISTOCENE ASSEMBLAGES

| Pollen type | Pliocene (%) | Pleistocene (%) |
|---|---|---|
| Chenopod type | 0 - 2.0 | 2 - 5 |
| Compositae | 0 - 10.5 | 19.5 - 64 |
| Gramineae | 0 - 17.5 | 14 - 23 |

(From Martin, 1973; 1969)

TABLE 3
THE MAJOR POLLEN GROUPS IN UPPER CAINOZOIC ASSEMBLAGES

| Pollen group | Palynomorphs listed in the Appendix |
|---|---|
| Total spores | All palynomorphs listed under spores (more than 16 types) |
| Total Gymnosperms | The 6 palynomorphs listed under Gymnosperm Pollen |
| Myrtaceae | *Myrtaceidites eucalyptoides*<br>*M. mesonesus*<br>*M. parvus*<br>Myrtaceae (undintified) |
| *Casuarina* | *Casuarina* spp. |
| *Nothofagus* | *Nothofagus, menziesii* pollen type<br>*Nothofagus, fusca* pollen type<br>*Nothofagus, brasii* pollen type |
| Chenopod-type | *Polyporina chenopodiaceoides* |
| Compositae | *Tubulifloridites pleistocenicus*<br>*Tubulifloridites* spp. |
| Cyperaceae | Cyperaceae |
| Gramineae | *Graminidites media* |

It is uncertain whether the Pliocene assemblages in western Victoria have a low herbaceous content as Harris (1971) does not present quantitative data. Hekel (1972) describes Pliocene assemblages in Queensland with high percentages of Compositae and the chenopod-type pollen. Consequently, the change from low to high percentages of herbaceous pollen types may be time-transgressive, occurring earlier in certain other regions than in south western New South Wales.

For the purposes of this paper, the assemblages of the Mooki Valley are correlated with those in south western New South Wales, and it is assumed that the change from low to high herbaceous pollen types approximates the Pliocene-Pleistocene boundary.

The frequency of palynomorphs in the assemblages are shown in the Appendix. The most abundant ones are placed into the major pollen groups shown in Table 3 and these are shown in Fig. 2.

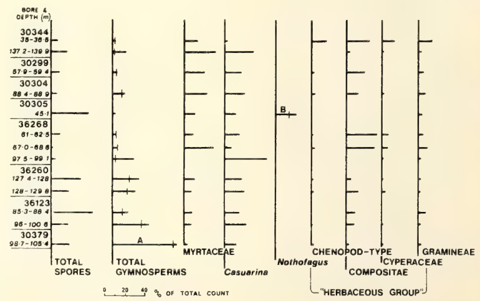


Fig. 2. Frequency of the major pollen groups of the Upper Cainozoic, expressed as percentages of total pollen count. For explanation of the pollen groups, see Table 3. A, *Araucariacites australis*. B, the *brassii* pollen type of *Nothofagus*.

The assemblage from Bore 30305 at 45.1 m is conspicuous with about 20% of *Nothofagus* including 14% of the *brassii* pollen type. It also has *Haloragis* which first appears in the upper part of the *Triporopollenites bellus* zone. Superficially, this indicates a late Miocene age, but the *brassii* type of *Nothofagus* is the only pollen type inconsistant with the *Nothofagus* phase of the Upper Pliocene. Whether this assemblage is late Miocene or a regional variant of the *Nothofagus* phase cannot be resolved on the present evidence. It would require a number of samples from the same bore, e.g. the Myrtaceae-*Casuarina* phase above and below to establish that it is the *Nothofagus* phase of the Pliocene. There is a third possibility, viz. that the *brassii* pollen type has been introduced into a Pliocene assemblage by the recycling of pollen through the erosion of older Tertiary deposits further upstream. For the present purposes, this assemblage is regarded as anomolous.

In all the other assemblages, the total spore group is usually moderately low although two assemblages have 30-40%. The total gymnosperm group may be low to fairly high, with one sample containing over 50%. Araucariaceae (or *Araucariacites australis*) usually accounts for the bulk of the gymnosperm pollen. Myrtaceae and *Casuarina* are usually less than 20%. The remaining groups, chenopod-type, Compositae, Cyperaceae and Gramineae are usually low with occasionally values of 10-20%.

From the frequencies of herbaceous taxa in the Pliocene and Pleistocene assemblages, only one sample, Bore 30344 at 35-36.5 m is Pleistocene. Two assemblages, Bore 36268 at 61.0 - 62.5 m and 67.0 - 68.6 m, have about 30% of Compositae, and this is unusually high, considering that the chenopod-type and Gramineae are both low. These two assemblages are still considered to be Pliocene, as it is obvious that the application of this method cannot be too rigid for there would have been local variation in the Pliocene/Pleistocene vegetation.

The Cyperaceae has been included in the herbaceous group in Fig. 2 because it follows the same trend as the other three groups. It is uncertain whether the Cyperaceae could be used as an indicator of the Pliocene/Pleistocene or whether this has local significance only.

The assemblages of the Mooki Valley show a good general agreement with those of south western New South Wales. The most striking difference is the abundance of Araucariaceae in the Mooki, up to 50% compared with a maximum of 7.5% in south western New South Wales. *Tubulifloridites pleistocenicus* appears to be restricted to the Pleistocene in south western New South Wales, but this is not the cast in the Mooki Valley where it is found in the Pliocene as well.

DISCUSSION

Fig. 3 shows a N-S section through the Mooki Valley. The bedrock in the two most south westerly bores contains the *P. reticulatus* assemblage, of the Late Permian, or very base of the Narrabeen Group equivalents. In all other bores which yielded a bedrock assemblage, it is the older stage 5 or "Upper Coal Measures".

The Tertiary assemblages are all found in the grey clays and all are Pliocene with the possible exception of the one anomolous sample. In at least two bores, and possibly three the Pliocene assemblages directly overlie the bedrock and these bores are located in the deepest part of the valley. This suggests that deposition of the

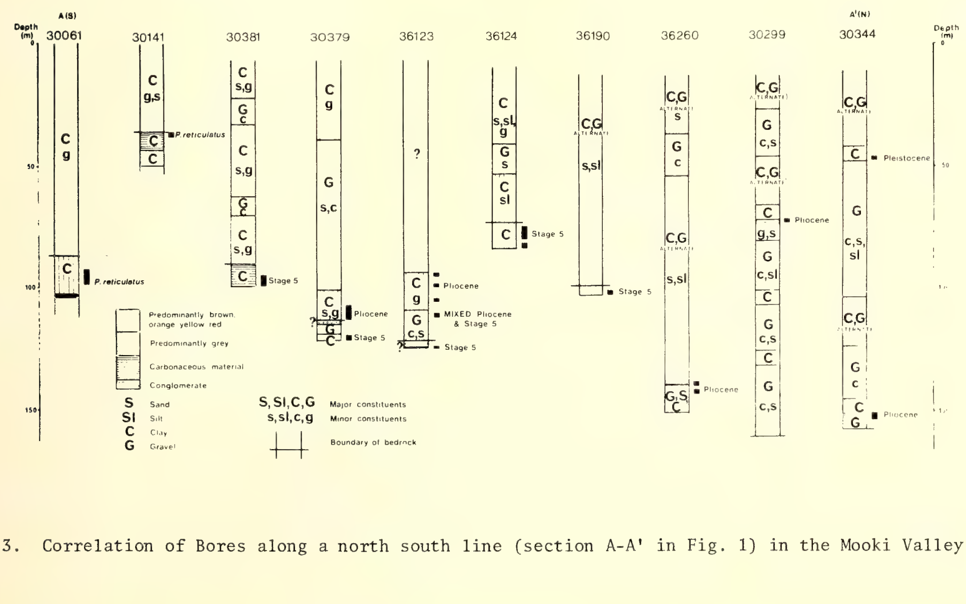

Fig. 3. Correlation of Bores along a north south line (section A-A' in Fig. 1) in the Mooki Valley.

APPENDIX

DISTRUBUTION OF UPPER CAINOZOIC PALYNOMORPHS (PERCENTAGE) (BORES ARRANGED IN ORDER N→S, THEN W→E)

| SPORES | Bores and Depth (m) | 30344 35.0 - 36.5 | 137.2-139.9 | 30299 57.9 - 59.4 | 30304 88.4 - 89.9 | 30305 45.1 | 36193 137.2-138.7 | 36268 61.0 - 62.5 | 67.0 - 68.6 | 97.5 - 99.1 | 36260 127.4-128.0 | 128.0-129.8 | 36123 85.3 - 88.4 | 96.0 -100.6 | 30379 98.7 -105.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cingulatisporites bifurcatus* (Couper) Martin, 1973 | | 0.6 | | 1 | 1 | | + | 1 | | | 3.3 | 5.0 | 2.4 | 1 | 1 |
| *Cyathea paleospora* Martin, 1973 | | | 7.9 | 3 | 1 | 7 | | 1 | | 1 | 18.7 | 9.5 | 20.7 | 11 | 5 |
| *Cyathidites subtilis* Stover & Partridge, 1973 | | | | | | 1 | | | | | | | | | |
| *Deltoidospora granulomargo* Martin, 1973 | | | | | | | | | | | 0.7 | | 1.2 | 1 | |
| *D. inconspicua* Martin, 1973 | | | | 1 | 3 | 6 | + | 4 | 2 | 2 | 0.7 | 1.0 | 2.4 | 2 | 3 |
| *Gleichenia circinidites* Cookson, 1953 | | | 1.0 | | | 2 | | | | 1 | | | | | |
| *Laevigatosporites ovatus* Wilson & Webster, 1946 | | | 4.4 | | | 3 | | 2 | | 1 | 2.0 | | 8.5 | 1 | 2 |
| *Lycopodium* sp | | | 0.5 | | | | | | | | | | | | |
| *Matonisporites ornamentalis* (Cookson) Stover & Partridge, 1973 | | | 2.0 | 1 | | 7 | | | | | | | 2.4 | 1 | 1 |
| *Polypodiidites* sp. | | | | | | | + | | | | | | | | |
| *Pteris* - type | | | | | | 2 | | | | | 2.0 | 2.0 | 0.6 | | 5 |
| *Reticulatisporites cowrensis* Martin, 1973 | | 1.2 | | | | 1 | | 1 | | | | | | | |
| *R. echinatus* Martin, 1973 | | | | | | | | | | | 0.7 | 0.5 | | | |
| *Rouseisporites* sp | | 0.6 | | 3 | 2 | | | | | | 0.7 | 0.5 | | | 1 |
| *Sphagnum* type | | | | | | | | | | | | | 0.6 | | |
| *Thelipteris-Asplenium* type | | | | | | | | | | | | | 0.6 | | |
| Unidentified spores | | 4.8 | 0.5 | | | | | | | | | | 0.6 | | 1 |
| GYMNOSPERM POLLEN | | | | | | | | | | | | | | | |
| *Araucariacites australis* Cookson, 1947 | | 3.0 | 3.0 | 4 | 10 | 1 | | 4 | 5 | 3 | 16.7 | 14.4 | 10.9 | 29 | 50 |
| Cupressaceae | | 0.6 | 3.5 | | | | | | | | | 2.0 | 1.2 | | |
| *Dacrydium florinii* (Cookson & Pike) Cookson, 1956 | | | | | | 1 | | | | | | | | | |
| *Microcachryidites antarcticus* Cookson, 1947 | | | | | | | | | | | 0.7 | | | | |
| *Phyllocladus palaeogenicus* Cookson & Pike, 1954 | | | 1.5 | | | | | | | 2 | 1.4 | | | | |
| *Podocarpus australiensis* (Cookson & Pike) Martin 1973 | | | 1.0 | | | | | | | 2 | 1.4 | 1.0 | | | |
| *P. elliptica* (Cookson) Martin 1973 | | | 4.4 | 1 | 3 | 1 | | | | 13 | 5.3 | 6.5 | 3.6 | 7 | 3 |
| ANGIOSPERM POLLEN - DICOTYLEDON | | | | | | | | | | | | | | | |
| *Acacia myriosporites* Cookson, 1954 | | | 0.5 | 3 | | | | | | | | | 0.6 | 1 | 6 |
| *Banksia* sp | | | 0.5 | | | | | | | | | | | | |
| *Casuarina* spp | | 2.4 | 27.7 | 16 | 19 | 10 | + | 13 | | 40 | 16.0 | 19.4 | 12.8 | 20 | 9 |
| *Cupanieidites orthoteichus* Cookson & Pike, 1954 | | | | | | 1 | | | | | | | | | |
| *Dilwynites granulatus* Harris, 1965 | | | | | | | | | | | | 0.5 | | | |
| *Drimys tetradites* Martin, 1973 | | | 1.0 | | | | + | | | | 1.4 | 0.5 | | 2 | 1 |
| *Geranium* sp | | | | | | | | | | | | | | | 1 |
| *Haloragis haloragoides* (Cookson & Pike) Martin, 1973 | | | 0.5 | 7 | 3 | | + | 7 | 2 | 1 | 2.0 | 3.5 | 1.2 | 1 | 1 |
| Labiateae (polycolpate type) | | | | | | | | | | | | 0.5 | | | |
| *Leucopogen* type | | | | 1 | | | | | | | | | | | |
| Loranthaceae cf *Decaisnina* sp | | | 0.5 | | | | | | | | | | | | |
| *Micrantheum spinyspora* Martin, 1973 | | | | 3 | | | | | | | | | | | |

| ANGIOSPERM POLLEN - DICOTYLEDON (CONT.) | Bores and Depth (m) | 30344 35.0 - 36.5 | 137.2-139.9 | 30299 57.9 - 59.4 | 30304 88.4 - 89.9 | 30305 45.1 | 36193 137.2-138.7 | 36268 61.0 - 62.5 | 67.0 - 68.6 | 97.5 - 99.1 | 36260 127.4-128.0 | 128.0-129.8 | 36123 85.3 - 88.4 | 96.0 -100.6 | 30379 98.7 -105.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Myriophyllum* sp | | | | | | | | | | | | 1.5 | | | |
| *Myrtaceidites eucalyptoides* Cookson & Pike, 1954 | | 11.4 | 1.0 | 1 | 2 | 1 | | | 1 | | | 1.5 | | | |
| *M. eucalyptoides* Cookson & Pike, 1954, small form | | | 12.4 | | | | | 3 | | | | | | | |
| *Myrtaceidites mesonesus* Cookson & Pike, 1954 | | | 0.5 | | | | | | | | | | | | |
| *M. parvus* Cookson & Pike, 1954 | | | 4.0 | | | 3 | | 1 | | | | | | | |
| Myrtaceae (unidentified) | | 0.6 | 11.9 | 1.8 | 19 | 6 | | 6 | 27 | | 8.7 | 4.0 | 6.7 | 6 | 1 |
| *Nothofagus, menziesii* pollen type | | | | | | 6 | | | | | | | | | |
| *Nothofagus, fusca* pollen type | | | | | | 1 | | | | | | | | | |
| *Nothofagus, brassii* pollen type | | | | | | 14 | | | | | | | | | |
| *Pelargonium* sp | | | | | | | | | | 2 | | | | 1 | |
| *Polygonium* sp (pantoporate type) | | 0.6 | | | | 1 | | | | | | | | 1 | |
| *Polyporina chenopodiaceoides* Martin, 1973 | | 13.2 | | 1 | 3 | | | 1 | 3 | | 0.7 | 2.5 | | 1 | 1 |
| *P. granulata* Martin, 1973 | | 2.4 | | | | | | 2 | | | 2.7 | 1.0 | 1.2 | 3 | |
| *Proteacidites ivanhoensis* Martin, 1973 | | | 0.5 | | | 1 | | | | | | | | | |
| *P. subscabratus* Couper, 1960 | | | 0.5 | | | 1 | | | | | | | | | |
| *Quintinia psilatispora* Martin, 1973 | | | | | | 1 | | | | | 0.7 | | | | |
| *Stephanocolpites oblatus* Martin, 1973 | | | 0.5 | | | | | | | | 0.7 | | | | |
| *Tricolporopollenites similis* Martin, 1973 | | | | 1 | | | | | | | | | | | |
| *T. substriatus* Martin, 1973 | | | | | | 1 | | | | | | | | | |
| *T. transversalis* Martin, 1973 | | | 0.5 | | | | | | | | 0.7 | | | | |
| *Tricolporites microreticulatus* Harris, 1965 | | | | | | 1 | | | | | | | | | |
| *Triorites orbiculatus* McIntyre, 1965 | | | | 3 | 1 | | | | | 19 | 3.3 | 0.5 | | | |
| *Tubulifloridites pleistocenicus* Martin, 1973 | | 1.2 | | | 1 | | | 2 | | | | 0.5 | + | | |
| *Tubulifloridites* spp. | | 20.3 | 1.0 | 19 | 9 | | | 30 | 30 | | 3.3 | 9.4 | 6.7 | 7 | 3 |
| ANGIOSPERM POLLEN - MONOCOTYLEDON | | | | | | | | | | | | | | | |
| Cyperaceae | | 13.8 | 1.0 | 4 | 1 | | | 7 | 5 | 2 | 0.7 | 0.5 | 3.0 | 2 | 1 |
| *Graminidites media* Cookson, 1947 | | 13.8 | 1.5 | | 6 | 2 | | 5 | 8 | 1 | 0.7 | 4.5 | 4.9 | 2 | 2 |
| *Liliacidites* sp | | 3.0 | | | | | | | | | | | | | |
| Restionaceae | | 0.6 | 0.5 | | | | | | 1 | | | | | | |
| *Sparganiaceaepollenites barungensis* Harris, 1972 | | 0.6 | 0.5 | | | 2 | | | | | | 0.5 | | | |
| UNIDENTIFIED POLLEN | | | | | | | | | | | | | | | |
| Polycolpate | | 0.6 | | | | | | | | | 0.7 | | | | |
| Tricolporate/Tricolpate | | 4.2 | 3.0 | 2 | 14 | 5 | | 8 | 8 | 7 | 2.7 | 5.0 | | | 1 |
| Triporate | | | | 2 | | | | | | | | 1.0 | | | |
| Monosulcate | | | 0.5 | | | | | | | | | 0.5 | | | |
| Others | | 0.5 | | 5 | | 2 | | 2 | 2 | 2 | 1.4 | 0.5 | 3.7 | | |

+ POLLEN CONTENT TOO LOW FOR COUNTING.

Tertiary alluvium did not start until the Pliocene and that uplift along the Mooki Thrust System did not immediately follow the outpouring of Oligocene basalts, but it occurred much later. The one anomolous assemblage which may be late Miocene is also closely associated with bedrock. On this evidence, Tertiary uplift along the Mooki Thrust System may be late Miocene-Pliocene. The one Pleistocene assemblage is from a bore north of the Namoi River.

The widespread occurrence of brown-yellow-orange clays suggests that the climate was either moderately arid or there was a marked seasonal drought. The occassional grey clays probably mark the position of an old billabong, lake or back swamp which remained permanently wet, acting as a natural pollen trap. The relatively low occurrence of the herbaceous taxa in the Pliocene assemblages indicates mostly closed forests. Today, *Araucaria* is found in the drier kinds of closed forests of eastern Australia. The Pleistocene assemblage, with its higher content of herbaceous taxa indicates a more open forest or savannah woodland. That only one Pleistocene assemblage has been encountered in all of these bores suggests fewer back swamps etc. in the Pleistocene landscape, that is, a drier climate than that of the Pliocene.

ACKNOWLEDGMENTS

I am indebted to the Water Resources Commission of New South Wales who supplied the financial assistance and raw materials for this study. Mr. G. Gates of the Water Resources Commission of New South Wales provided information and valuable comment on the paper.

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# REPORT OF COUNCIL FOR THE YEAR ENDED 31st MARCH 1979

Presented at the 112th Annual General Meeting of the Society held on 4th April 1979.

INTRODUCTION

The activities of the Society have continued at a very satisfactory level during the year. As will be seen from the annual financial statement and balance sheet the financial position of the Society is, however, still far from satisfactory. The modest increase in subscription rates, effective next financial year will only partly redress the imbalance and Council is very conscious that expenditure must be minimal in the coming year.

MEETINGS

Council held 12 meetings during the year and dealt with all the business matters of the Society. One of the meetings was called especially to consider certain proposals in connection with the raising funds to reduce the debt owing on the Science Centre; this is a matter which has still to be resolved and further reference is made in the section of this Report dealing with the Science Centre. Attendance of members of Council at these meetings ranged from 11 to 17.

Nine general monthly meetings were held during the year together with four special meetings, namely the "Pollock Memorial Lecture" (held in conjunction with the University of Sydney), the "Liversidge Memorial Lecture" (held in conjunction with the University of Sydney), the "Liversidge Memorial Lecture", an "Evening at the Macleay: and a lecture on "Sir Joseph Banks". Abstracts of these meetings will be published in the Journal and Proceedings; abstracts of the lectures given have already been published in the Society's Newsletter. The average attendance at the general monthly meetings, namely 41, and virtually the same as last year, is considered by Council to be disappointing. Members and guests attending have found the lectures to be interesting and stimulating and Council expresses its sincere thanks to all the speakers for the high standard of their addresses.

ANNUAL DINNER

The Annual Dinner was held at the Sydney Hilton Hotel on 21st March 1979 and was attended by 83 members and guests. The guest speaker was Mrs. Nancy Bird Walton, O.B.E., A.R.Ae.S., the title of her address being "The Air Ambulance - how it got off the ground."

AWARDS

The following awards for 1978 were made:

James Cook Medal: Sir Lawrence J. Wackett
Edgeworth David Medal: Joint award to Dr. T.W. Cole and Dr. M.G. Clark
Clark Medal: Professor D.T. Anderson, F.R.S.
The Society Medal: Mr. M.J. Puttock
Archibald D. Olle Prize: Mr. D.S. King
Liversidge Research Lectureship: Professor H.C. Freeman
Pollock Memorial Lectureship (in conjunction with University of Sydney): Professor R.N. Bracewell
Summer School in Medicine Essay Prizes:
Miss Teresa Pirola
Miss Penny Gilson
Miss Josephine Muscolino

SUMMER SCHOOL

The Society held only one Summer School, in January, for fifth form Secondary Students. The School was in the field of Medicine with the theme title "Preserving and Restoring Health" and was arranged in cooperation with the Royal Prince Alfred Hospital, Camperdown. 69 students from 25 secondary schools attended the 5-day school which was based at the Royal Prince Alfred Hospital and visits to the Lidcombe Laboratories of the Health Commission of New South Wales and to the research and production sections of a leading manufacturer of pharmaceutical products.

MEMBERSHIP

The membership of the Society at 31 March 1979 was:

| | |
|---|---|
| Honorary Members | 13 |
| Life Members | 39 |
| Members | 341 |
| Associate Members | 58 |
| Company Member | 1 |

PUBLICATIONS

Volume 111 of the Journal and Proceedings was published during the year.

There were 10 issues of the Society's monthly Newsletter. Council expresses its sincere thanks once again to Dr. J. Dulhunty who has continued to assist in collecting and editing the feature articles which have covered a wide range of interesting topics.

LIBRARY

There has been a marked increase in the number of requests on the Library for material; some 243 such requests have been processed involving 3726 photocopies. It is of interest to note that the distribution of requests was identical to that reported last year, namely 94% were received from Commonwealth and State Departments, Universities, Companies, Hospitals and other organizations and 6% only from members of the Society.

Although the Library is only open two full days a week the services continue to be maintained at a high level by the Librarian, Mrs. G. Proctor.

FINANCE

The Society's annual accounts for 1978 show a deficit on the year's operations of $5520.69, comprising $4097 applied to operations and $1424 in

items not involving outlay of funds. The deficit was due in large measure to four causes:

(1) The N.S.W. Government failed to provide the annual grant which has always played a significant part in the Society's finances in the past. $3000 had been budgeted for.

(2) Net expenditure on publishing the Journal and Proceedings exceeded budget by about $1000 due to a failure to ensure that the format of the Journal would be such as to attract the publishing subsidy offered by the Australian Government under the book bounty scheme.

(3) Due to unexpected factors losses totalling $459 were incurred on the 1978 annual dinner and the reprints of papers in the Journal.

(4) No income was received from Science House Pty. Ltd. This was of course anticipated; but members are reminded that the Society used to benefit annually by an amount greater than the present deficit from its investment in the old Science House. It is a source of continuing regret that decisions taken for the apparent good of the Society nearly a decade ago have been followed by the present situation in which vital income is not forthcoming and there is a real risk that the Society's entire investment of $416,991 in the Science Centre may be lost.

On the positve side, it is pleasing to be able to report that the thirty or so other budget items were kept close to their respective targets. In particular, another reduction in Salaries was achieved despite the general increase in wage levels. It is doubtful that any further reduction in this area will be possible without seriously curtailing the Society's operations. The item: Fees for secretarial services has also been reduced by transferring the publishing of the Newsletter to the Society's own office from July 1978. Postage now represents two-thirds of the cost of sending out the Newsletter. Members will understand that in the circumstances an increase in the membership fee in 1979 was unavoidable.

The proceeds of Dr. Codrington's magnificent bequest were successfully invested as were smaller amounts generously donated during the year. Another welcome, but anonymous, donation assisted greatly with the unavoidable purchase of a new photocopier for joint use with the Linnean Society. Our investments now total $67,580 and since the income they yield is vital to the Society's survival they must not be frittered away in making good deficits on future operations. Any donations to the Society's Library Fund, which would be tax-deductible, will be most welcome.

SCIENCE CENTRE

The Science Centre has continued to make significant progress in providing the secretarial services and conference and meeting-room facilities as envisaged in its establishment as the successor to the old Science House. Additionally it has obtained recognition by the Commonwealth Foundation as one of the major Professional Centres within the Commonwealth of Nations and hopefully will be able to play a significant role in cooperating with those Professional Centres being developed in the neighbouring nations of Asia and the Pacific.

Despite steady, and continuing, improvements in the 'trading' operations of the Centre it has still not proved possible to meet the full interest owing on the loan obtained from the Commonwealth Bank. This is a matter of extremely grave concern to the Directors of the Company, Science House Pty. Ltd., set up jointly by the Linnean and Royal Societies of N.S.W. Recognizing that the result of the original appeal for funds was totally inadequate the Directors are investigating a proposal to establish an appropriate Foundation which would attract donations of sufficient magnitude to have a significant impact on the financial situation of the Centre.

Your Council, and your four Directors on the Board of Science House Pty. Ltd. continue to believe that the concept of the Science Centre is sound, that it continues the purpose for which the old Science House was established in 1931 (and for which the N.S.W. Government gave the grant of the land in 1928) and, therefore, that every possible avenue for the raising of funds must be pursued with vigour.

ACKNOWLEDGEMENTS

In acknowledging the excellent work of its two part-time members of staff, namely Mrs. Judith Day in the general running of the office and Mrs. Grace Proctor as Librarian, Council would also like to record its appreciation of the very courteous manner in which these ladies accomplish their task.

Council also wishes to record its appreciation of the efforts of those many people, both members and non-members of the Society, who have contributed to the success of all the activities during the year; special thanks are due to all those who made the Summer School in Medicine such an outstanding success.

ABSTRACT OF PROCEEDINGS
1978 - 1979

The annual general meeting, monthly meetings and a special general meeting were all held in the Science Centre. Threee additional meetings were conducted in other locations. Abstracts of the proceedings of all the meetings are given below, classified by meeting place.

LOCATION

Science Centre, 35 Clarence Street, Sydney.

APRIL 5th

111th Annual General Meeting. The President, Mr. W.H. Robertson, was in the chair and 61 members and visitors were present.

The Annual Report of Council and the Annual Statement of Accounts were adopted. Four papers were read by title only.

The Clarke Medal was awarded to Dr. A.F. Trendall; the Edgeworth David Medal to Professor R.A. Antonia; the James Cook Medal to Emeritus Professor I.A. Watson; the Society's Medal to Mr. J.W. Humphries; the Walter Burfitt Medal and Prize to Dr. A. Kerr.

Messrs. Wylie and Puttock, Chartered Accountants were elected Auditors.

The Presidential Address "The Minor Planets" was given by Mr. W.H. Robertson.

The incoming President, Professor F.C. Beavis was installed and introduced to members.

MAY 3rd

907th General Monthly Meeting. The President, Professor F.C. Beavis, was in the chair and 33 members and visitors were present. 5 new members were elected. Two papers were read by title only.

An address "Where Air Pollution goes to in Sydney" was given by Professor Edward Linacre, School of Earth Sciences, Macquarie University.

JUNE 7th

908th General Monthly Meeting. The President, Professor F.C. Beavis, was in the chair and 58 members and visitors were present. 2 new members were elected.

An address "Genetic Engineering" was given by Professor R.G. Wake, McCaughey Professor of Biochemistry, University of Sydney.

JULY 5th

909th General Monthly Meeting. The President, Professor F.C. Beavis, was in the chair and 45 members and visitors were present. 3 new members were elected and Council announced the admittance of 1 new associate member.

Council recorded with pleasure the award of Knight Bachelor to Sir John Proud for services to the mining industry; Sir John has been a member of the Society for 33 years.

An address "Recent Archaeological Research in the Middle East" was given by Professor J.B. Hennessy, Department of Archaeology, University of Sydney.

AUGUST 2nd

910th General Monthly Meeting. The President, Professor F.C. Beavis, was in the chair and 25 members and visitors were present. 2 new members were elected, and Council announced the admittance of 1 new associate member. One paper was read by title only.

An address, "Noise and Noise Control in our Society", was given by Mr. Campbell Steele, Chartered Engineer, Campbell Steele and Associates.

SEPTEMBER 6th

911th General Monthly Meeting. The Vice-President, Mr. W.H. Robertson, was in the chair and 28 members and visitors were present. 1 new member was elected. Five papers were read by title only. Council announced with gratitude an anonymous donation of $1000 to the Library Fund.

An address, "Design of Buildings for Best Use of the Sun" was given by Dr. J.J. Greenland, Senior Lecturer, School of Architecture and Building, N.S.W. Institute of Technology.

OCTOBER 4th

912th General Monthly Meeting. The President, Professor F.C. Beavis, was in the chair and 47 members and visitors were present. 3 new members were elected and Council announced the admittance of 1 new associate member.

An address, "Recent Developments in Photographic Technology" was given by Dr. Melvyn Forbes, Research Scientist, Kodak Research Laboratories.

NOVEMBER 1st

913th General Monthly Meeting. The Vice-President, Mr. W.H. Robertson, was in the chair and 44 members and visitors were present. 1 new member was elected.

A symposium was held with the theme "Our Ocean Resources". The panel of speakers comprised Dr. D.D. Francois, Director of the New South Wales State Fisheries; Dr. W.G.H. Maxwell, Executive Director, Australian Petroleum Exploration Association Ltd.; Mr. Gerrard Brennan, Assistant Legal Advisor, Dept. of Foreign Affairs and Deputy Head of Australian Law of the Sea Delegation.

DECEMBER 6th

914th General Monthly Meeting. The Vice-President, Mr. W.H. Robertson, was in the chair and 27 members and visitors were present. 3 new members were elected. One paper was read by title only. Council announced with regret the death of Mr. A.F. Day a former member of the Society for many years and editor of the Subject Index of the Journal and Proceedings (1867 to 1966).

An address "Detection of Philatelic Forgeries" was given by Mr. Derek Yardley, Director, Harmers

of Sydney Pty. Ltd., International Stamp Dealers.

FEBRUARY 8th

Special General Meeting. The President, Professor F.C. Beavis was in the chair and 39 members and visitors were present.

An address, "Sir Joseph Banks: an assessment of his place in the energent science of Western Europe" was given by Mr. H.B. Carter, B.V.Sc., F.R.S.E., F.L.S., F.I.Biol.

LOCATION

The Wallace Theatre, The University of Sydney.

MAY 15th

The Pollock Memorial Lecture was given by Professor R.N. Bracewell, Professor of Electical Engineering, Stanford University, Stanford, California, U.S.A., the title of the address being "Life in Space".

LOCATION

New South Wales Institute of Technology.

JULY 19th

The Liversidge Memorial Lecture was given by Professor H.C. Freeman, Professor of Inorganic Chemistry, University of Sydney, the title of the address being "Elegance in Molecular Design: The Copper Site of a Photosynthetic Electron-Transfer Protein".

LOCATION

The Macleay Museum, The University of Sydney.

SEPTEMBER 20th

Members and guests attended a private viewing of the exhibition "The Discovery of Australian Animals". Dr. P.J. Stanbury, Curator of the Macleay Museum, gave a short talk on the exhibition.

## OBITUARY

### AUSTIN KEANE

On 13th March, 1979, Austin Keane, a past President of the Royal Society of New South Wales, died in Wollongong Hospital. Though he had been ill for some time, the suddenness of his death at the age of 51 has shocked his many friends and colleagues whose sympathy is extended to his wife, Lorna, and to their two children, Phillip and Joanne.

Austin was born on 19th August, 1927. After graduating in 1949 from the University of Sydney as B.Sc. with honours in Mathematics and the University Medal, he was first appointed as Lecturer in Mathematics at Sydney Technical College before transferring to the University of New South Wales with the formation of that body. While in charge of the Mathematics and Physics Departments at that University's Wollongong Branch, he continued his postgraduate studies and took the degrees of M.Sc. (Sydney) in 1951 and Ph.D. (N.S.W.) in 1956. After teaching at the Kensington campus until the end of 1959, he was seconded as executive officer of the Institute of Nuclear Engineering to plan and lecture in post-graduate courses until 1961, when he joined the Australian Atomic Energy Commission as Head of Theoretical Physics Section at the Lucas Heights Research Establishment. In 1965 he moved to the University of Wollongong as Professor of Mathematics, which post he held until his retirement in 1978 and appointment as Emeritus Professor.

He joined the Royal Society of New South Wales in 1955 and served on the Council from 1963 to 1972 with a break of only twelve months. Elected as President for 1968-69, his term saw the publication of the Society's Centenary Volume and the formation of the South Coast Branch of the Society. His contributions to the Journal and Proceedings were four research papers dealing with molecular vibrations, coal mine ventilation, neutron absorption in fission reactors and with an equation arising in renewal theory.

While forming only a small part of his published work - some 80 papers and reports as well as one textbook and the editorial supervision of others - those four papers indicate the breadth of his research interests. In all of these he was the classical applied mathematician - one who uses mathematical techniques to study the behaviour of model systems and then tries to deduce solutions to problems in the real world which the models imitate. He got great pleasure from this kind of mathematics and from doing it well; moreover, he taught his many research students how to get the same pleasure.

Enthusiasm, cheerfulness and boundless generosity were among his many endearing qualities. The dignity with which he accepted the restrictions imposed by his last illness demonstrated the strength of character which hes many friends will remember. His untimely passing is a great loss to us.

B. Clancy.

## CITATIONS

### EDGEWORTH DAVID MEDAL

Dr. Trevor W. Cole graduated in 1965 as Bachelor of Engineering with First-Class Honours in Electrical Engineering in the University of Western Australia. In 1970 he was awarded a Ph.D. at the Cavendish Laboratory in the University of Cambridge. He is currently attached to the Division of Radiophysics, C.S.I.R.O.

Dr. Cole's outstanding contribution has been in the field of radio astronomy; notably his part played in the development of the Acousto-Optical Spectrograph. This instrument which employs a laser beam modulated by ultrasonic waves has revolutionised radio astronomy spectroscopy. It is an essential piece of equipment in the current search for interstellar glycine being made by Monash University and the Division of Radiophysics. In a series of original experiments, Dr. Cole has also been looking into the application of holographic methods to aperture synthesis radio telescopes.

Dr. Cole has published over 40 papers in the field of radio astronomy. The Royal Society of New South Wales recognises his outstanding contribution to Australian science in this joint award of the Edgeworth David Medal.

Dr. Michael G. Clark is Senior Lecturer in the Clinical Biochemistry Unit, Flinders Medical School, South Australia. He is a Biochemist who has gained international recognition for his research on metabolic regulation. Dr. Clark graduated in 1968 as Bachelor of Science with First-Class Honours in Biochemistry in the University of New South Wales, and Ph.D. from the same University in 1972.

Dr. Clark's work on substrate cycling has shown the importance of the fructose 1-6 diphosphatase-phosphofructose Kinase cycle as a site of regulation of hepatic gluconeo-genesis by glucagon. This work was subsequently extended to a study of the redox state in hepatocytes and has led to a hypothesis that the efficiency ofthe two hormones glucagon and insulin may be dependent on the redox state of the liver. He has been conducting studies also with isolated beating heart cells.

Dr. Clark has published over 70 papers mainly relating to work carried out in Australia. In awarding the Edgeworth David Medal jointly to Dr. Clark, the Royal Society of New South Wales recognises an outstanding young scientist.

### THE CLARKE MEDAL

The Clarke Medal for distinguished work in the Natural Sciences done in or on the Australian Commonwealth and its territories is awarded to Professor D.T. Anderson, F.R.S.

Professor Anderson is a graduate of the University of London, where he completed his Ph.D. studies under Professor S.M. Manton, F.R.S. Following a period of National Service, he was appointed a Lecturer in Zoology at the University of Sydney in 1958. There he has risen through the ranks, being appointed Professor of Biology in 1972.

Professor Anderson's graduate studies on the embryology of polychaete worms led to two parallel research interests in Australia. The first and the more important focussed on the comparative embryology of Australian species of annelids and anthropods, none of which had been previously investigated. These studies led to a major advance in the understanding of the evolutionary relationships and phylogenetic history of these major groups of invertebrates. His important book on Embryology and Phylogeny of Annelids and Anthropods, published in 1973, showed that the embryological evidence favours the view that the three major types of anthropod (insects, crustaceans and chelicerates (including arachnids)) evolved independently of one another, from separate Precambrian worm-like ancestries.

Professor Anderson's other major contribution to zoology has been his pioneering investigations of the reproduction and life cycles of some 40 species of Australian intertidal invertebrates, an area that was almost completely neglected before 1958. These studies have provided the bases on which the work of almost all other investigators has subsequently been built.

For his distinguished contributions to zoology, Professor Anderson was elected a Fellow of the Royal Society of London in 1977. He is also on the editorial boards of two international journals.

Professor Anderson is widely acclaimed by his peers as being the foremost zoologist in Australia today. He is a worthy recipient of the Clarke Medal.

## THE JAMES COOK MEDAL

The James Cook Medal for outstanding contributions to Science and Human Welfare in and for the Southern Hemisphere is awarded in 1979 to Sir Lawrence James Wackett.

A Science graduate from the University of Melbourne, Sir Lawrence was the founder, in 1921, of the R.A.A.F. Experimental Station where he pioneered the design and construction of aircraft in Australia. This led to his appointment in 1936 as first Director of the Commonwealth Aircraft Corporation, a position he was to hold with distinction for twenty-five years.

In a climate that was initially highly sceptical, the Corporation, under his inspiring and enterprising leadership, demonstrated that Australian industry could master the advanced technology needed to mass produce aircraft. Among the planes manufactured in those formative years were the Wirraway, the Wackett trainer, the Boomerang and the Mustang. The production of these aircraft at a critical period in the defence of Australia was an outstanding contribution to the Australian war effort in the Pacific area. Two of these aircraft, the Wackett trainer and the Boomerang, were designed by Sir Lawrence. Their performance demonstrated that he was an aircraft designer of the highest order. Subsequently, he supervised the design and construction of the Winjeel trainer and oversaw the introduction of jet power with the advent of the Sabre aircraft.

Among the honours bestowed upon him for his services in pioneering the aircraft industry in Australia are the Kernot Memorial Medal of the University of Melbourne (1959), the Jack Finlay National Award of the Institute of Production Engineers (1967), the Kingsford-Smith Memorial Medal (1975), and the Oswald-Watt Memorial Medal (1976).

In 1970, aged 74, Sir Lawrence suffered a severe accident. Following his experiences as a quadriplegic, he has applied himself successfully to the design and development of a range of aids for the disabled.

For his contributions to both the aviation industry and the disabled, Sir Lawrence Wackett is indeed a worthy recipient of the James Cook Medal.

## THE SOCIETY'S MEDAL

The Society's Medal for 1978 is awarded to Maurice James Puttock for his contributions to length and engineering Metrology, Science, and for services to the Society.

As a young man Maurice Puttock joined the Metrology Department, National Physical Laboratory, Teddington, England, from where at the time of the Second World War he enlisted in the R.A.F., later transferring to the Fleet Air Arm.

After the War ended, he graduated from London University obtaining a B.Sc.Eng. with Honours, rejoining National Physical Laboratory to become a Scientific Officer.

Coming to Australia in 1952 to continue his work at the National Standards Laboratory (now National Measurement Laboratory) he became Research Officer in charge of a group responsible for length measurements; he is a specialist in large scale metrology and has gained an international reputation for his work, which has covered many diverse fields some of which include the Metrology for Interscan, alignment of large steel Rolling Mills and alignment of large building structures.

One area in which he has excelled was in a project on the 210-foot Radio Telescope at Parkes where he worked in conjunction with Harry Minnett (now Chief of CSIRO Division of Radiophysics); resulting from this work the surface of the telescope has been upgraded to yield increased resolution by several orders of magnitude, for it was originally designed to receive hydrogen radiation at 210 mm wavelength and is now being used to receive radiations at 3 mm wave-lengths, a truly remarkable achievement!

Mr. Puttock now is a commissioner with the National Standards Commission and is currently a CSIRO representative on the Standards Association of Australia Council, he has also served on many of their Committees, currently being Chairman of both the Metrology Committee and also the Screw Thread Committee.

He is Chairman of the International Standards Organisation Technical Committee ISO/TC3, Limits and Fits (including Engineering Metrology); this has necessitated frequent visits overseas.

Maurice Puttock has published a number of papers in the field of Metrology, he has been a part-time lecturer at Sydney University, N.S.W. University of Technology (now University of N.S.W.) and Sydney Technical College, he also is the author of a standard Text Book on Engineering Metrology for Technical College students.

Maurice Puttock joined the Royal Society of New South Wales in 1960, being President in 1971, he has

served the Society with distinction and dedication on all of our committees, and has been Honorary Secretary for a number of years; he has always been willing to lend an ever helping hand and has given very wise guidance to us all in his quiet but forceful manner.

At the time of the resumption of the old Science House in Gloucester Street, Maurice became associated with the Resumption Committee, which later developed on to provide the New Science Centre in Clarence Street. Maurice Puttock is currently Deputy Chairman of the Board of Science House Pty. Ltd., and has given freely of his experience gained from being a Liason Officer between the CSIRO and the Architects and Engineers responsible for the New National Measurement Laboratory at Lindfield, - this has been most valuable; Maurice has also represented the Sydney Science Centre at overseas meetings.

Maurice Puttock is indeed a very worthy receipient of the Society's Medal.

## ARCHIBALD D. OLLE PRIZE

The Archibald D. Olle Prize is awarded to Mr. David S. King for his papers entitled "Proper Motions in the Region of NGC 3532" and "Proper Motions in the Region of the Galactic Cluster NGC 2516" which were judged the best papers published in the Journal of the Society during 1978.

Mr. King graduated B.Sc. with honours in applied mathematics in 1976 from the University of Sydney. Since then he has been an astronomer at Sydney Observatory. His chief fields of research are the astrometry and dynamics of star clusters.

## SUMMER SCHOOL IN MEDICINE

In January 1979, the Summer School in Medicine was organized in conjunction with the Royal Prince Alfred Hospital, and was attended by 69 students from Year 11 in 25 school in the Sydney area.

The students were invited to submit essays based on what they had learnt during the School. These essays have been assessed and the three judged to be the best were submitted by

Miss Teresa Pirola
Miss Penny Gilson
Miss Josephine Muscolino

Each of these young ladies has been presented with a copy of the Society's Centenary Volume

## ANNUAL REPORT OF NEW ENGLAND BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

### OFFICERS

| | |
|---|---|
| Chairman : | S.C. Haydon |
| Secretary Treasurer: | R.E. Gould |
| Committee: | R.D.H. Fayle, N.H. Fletcher, R.L. Stanton |
| Representative on Council: | R.L. Stanton |

### MEETINGS

The following meetings were held:

| | |
|---|---|
| 15 March, 1978: | "Some Present Aspects of China, with Special Reference to Medical Services", Dr. Harold Royle, Armidale. |
| 26 April, 1978: | "The Minor Planets", Mr. W.H. Robertson, N.S.W. Government Astronomer. |
| 4 October, 1978: | "Medicine and Religion; the Priest-Physician throoughout History", Professor John Duffy, University of Maryland. |
| 1 November, 1978: | "The Uranium Debate", Dr. John Kleeman, University of New England. |

### FINANCIAL STATEMENT

| | | |
|---|---|---|
| Balance as at 31 December 1977 | $300.94 | |
| Credit - Interest to 29 June 1978 | 5.07 | |
| - Interest to 29 December 1978 | 4.74 | |
| | | $310.75 |
| Debit - Advertising | $ 8.70 | |
| - Accommodation (2 guests) | 41.00 | |
| - Miscellaneous | 3.62 | |
| | | $ 53.32 |
| Balance as at 31 December 1978 | | $257.43 |

## ANNUAL REPORT OF THE SOUTH COAST BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

### OFFICERS

| | |
|---|---|
| Chairman: | B.E. Clancy |
| Secretary Treasurer: | G. Doherty |
| Representative on Council: | G. Doherty |

### MEETINGS

No meetings of the Branch were held during 1978.

### FINANCIAL STATEMENT

| | | |
|---|---|---|
| Balance as at 31 December 1977 | $ 49.03 | |
| Credit - Interest | $ 0.77 | |
| | | $ 49.80 |
| Balance as at 31 December 1978 | | $ 49.80 |

# FINANCIAL STATEMENTS FOR 1978

AUDITOR'S REPORT TO THE MEMBERS

In our opinion:

(a) the attached balance sheet and income and expenditure account are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1978 and of the results of the Society for the year ended on at date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provision of those Rules.

WYLIE AND PUTTOCK,
Chartered Accountants.

By ALAN M. PUTTOCK,
Registered under the Public Accountants
Registration Act, 1945 as amended.

BALANCE SHEET as at 31/12/78

| | | | | |
|---|---|---|---|---|
| | RESERVES | | | |
| 7199.57 | Library Reserve (note 2(i)) | | | 7199.57 |
| 416991.00 | Resumption Reserve (note 2(ii)) | | | 416991.00 |
| 2219.86 | LIBRARY FUND (note 2(iii)) | | | 2378.39 |
| 11918.67 | TRUST FUNDS (note 4) | | | 12912.84 |
| 76828.82 | ACCUMULATED FUNDS | | | 73307.24 |
| 515157.92 | TOTAL RESERVES AND FUNDS | | | 512789.04 |
| | Represented by: | | | |
| | CURRENT ASSETS | | | |
| 60.92 | Petty Cash Imprest | | 28.14 | |
| 1605.26 | Debtors for Subscriptions | 1329.22 | | |
| 1605.26 | Less Provision for Doubtful Debts | 1329.22 | - | |
| 2294.52 | Other Debtors & Prepayments | | 3220.67 | |
| 8020.27 | Interest Bearing Deposit | | 3820.39 | |
| 3295.41 | Cash at Bank | | 5574.83 | |
| 13671.12 | | | | 12644.03 |
| | Less: CURRENT LIABILITIES | | | |
| 5024.07 | Sundry Creditors and Accruals | | 7614.55 | |
| 6.17 | Life Members' Subscriptions - Current Portion | | 13.67 | |
| 68.14 | Membership Subscriptions Paid in Advance | | 124.69 | |
| 1365.67 | Subscriptions to Journal Paid in Advance | | 1287.60 | |
| 6464.05 | | | | 9040.51 |
| 7207.07 | NET CURRENT ASSETS | | | 3603.52 |
| | Add: FIXED ASSETS | | | |
| 7840.16 | Furniture, Office Equipment, etc. - at cost less Depreciation | | 8146.66 | |
| 2.00 | Lantern - at cost less Depreciation | | - | |

BALANCE SHEET as at 31/12/78

| | | | |
|---|---|---|---|
| 13600.00 | Library - 1936 Valuation | 13600.00 | |
| 12.00 | Pictures - at cost less Depreciation | 11.00 | |
| 21454.16 | | | 21757.66 |
| 28661.23 | | | 25361.18 |
| | Add: INVESTMENTS | | |
| 26580.00 | Commonwealth Bonds & Inscribed Stock | 27580.00 | |
| - | Loans on Mortgage | 40000.00 | |
| 40000.00 | Interest Bearing Deposits | - | |
| 66580.00 | | | 67580.00 |
| | Add: ASSOCIATED CORPORATIONS (note 3) | | |
| 1.00 | Shares - at Cost | 1.00 | |
| 419994.61 | Advances and Loans - Unsecrued | 419994.61 | |
| 419995.61 | | | 419995.61 |
| 515236.84 | | | 512936.79 |
| | Less: NON-CURRENT LIABILITIES | | |
| 78.92 | Life Members Subscriptions - Non-current portion | | 147.75 |
| 515157.92 | NET ASSETS | | 512789.04 |

F.C. Beavis, President A.A. Day, Hon. Treasurer

NOTES TO AND FORMING PART OF THE ACCOUNTS
for the year ended 31st December, 1978.

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1978. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

| | |
|---|---|
| Furniture | 7.5% |
| Office Equipment | 15.0% |

2. MOVEMENTS IN PROVISIONS AND RESERVES

(i) Library Reserve

| | 1977 | 1978 |
|---|---|---|
| Balance at 1st January, 1978 | \$7200 | \$7200 |
| Less | | |
| Movements | - | - |
| Balance at 31st December 1978 | \$7200 | \$7200 |

2. MOVEMENTS IN PROVISION AND RESERVES Continued

(ii) Resumption Reserve

| | 1977 | 1978 |
|---|---|---|
| Balance at 1st January 1978 | $416991 | $416991 |
| Less | | |
| Movements | - | - |
| Balance at 31st December 1978 | $416991 | $416991 |
| Represented by: | | |
| Shares in associated corporation | 1 | 1 |
| Loans to associated corporation | 416990 | 416990 |
| | $416991 | $416991 |

(iii) Library Fund

| | 1977 | 1977 | 1978 | 1978 |
|---|---|---|---|---|
| Balance at 1st January 1978 | | $93822 | | $2220 |
| Add Donations and Bank Interest | | 4793 | | 6421 |
| | | 98615 | | 8641 |
| Less Library purchases | 150 | | 856 | |
| Library fittings and equipment | 2547 | | 998 | |
| Paid re library facilities | 93198 | | 4409 | |
| Advance to general funds re preparation of subject index | 500 | | - | |
| | | 96395 | | 6263 |
| Balance at 31st December 1978 | | $ 2220 | | $ 2378 |
| Represented by: | | | | |
| Cash at bank | | 1049 | | 606 |
| Commonwealth Bonds | | 1300 | | 2300 |
| Owing by general funds | | (129) | | (528) |
| | | $ 2220 | | $ 2378 |

3. ASSOCIATED CORPORATIONS

The Society has entered into a joint venture with the Linnean Society for the establishment of a Science Centre for New South Wales and to facilitate this, a company, Science House Pty. Limited, has been formed in which each Society has 50% interest.

Advances and loans to the company have been on an interest free basis repayable at call. No material repayments are anticipated prior to 31st December 1979.

| | 1977 | 1978 |
|---|---|---|
| Total amount advanced | $512495 | $419995 |
| Less | | |
| Repaid during year | 92500 | - |
| Balance at 31st December 1978 | $419995 | $419995 |
| Representing: | | |
| Resumption reserve | 416990 | 416990 |
| Accumulated Funds | 3005 | 3005 |
| | $419995 | $419995 |

4. TRUST FUNDS

| | 1977 $ | Clarke Memorial $ | Walter Burfitt Prize $ |
|---|---|---|---|
| Capital | | | |
| Balance at 1st January 1978 | 7000 | 4800 | 3000 |
| Capitalisation of accumulated revenue | 4100 | - | - |
| Balance at 31st December 1978 | $11100 | $4800 | $3000 |
| Revenue | | | |
| Revenue income for period | 1194 | 471 | 295 |
| Less Expenditure | 649 | 25 | 199 |
| | 545 | 446 | 96 |
| Add Balance from 1977 | 4374 | - | 362 |
| | 4919 | 446 | 458 |
| Less Capitalisation | 4100 | - | - |
| Total Revenue | $819 | $446 | $458 |
| TOTAL TRUST FUNDS | $11919 | $5246 | $3458 |

| | Liversidge Bequest $ | Olle Bequest $ | Total $ |
|---|---|---|---|
| Capital | | | |
| Balance at 1st January 1978 | 2000 | 1300 | 11100 |
| Capitalisation of accumulated revenue | - | - | - |
| Balance at 31st December 1978 | 2000 | 1300 | 11100 |
| Revenue | | | |
| Revenue income for period | 196 | 242 | 1224 |
| Less expenditure | 6 | - | 230 |
| | 190 | 262 | 994 |
| Add Balance from 1977 | 222 | 235 | 819 |
| | 412 | 497 | 1813 |
| Less Capitalisation | - | - | - |
| Total Revenue | $412 | $497 | $1813 |
| TOTAL TRUST FUNDS | $2412 | $1797 | $12913 |

STATEMENT OF ACCUMULATED FUNDS

For the Year Ended 31 December 1978

| | | | |
|---|---|---|---|
| 419.37 | DEFICIT for year | | 5520.69 |
| 4793.16 | Donations & Interest to Library Fund | | 6420.64 |
| 37503.59 | Proceeds Estate Late Dr. J.F. Codrington | | 146.00 |
| 96394.82 | Transfer from Library Fund | | 6262.11 |
| 806.00 | Transfer from Long Service Leave Fund | | - |
| 35741.78 | Accumulated Funds - Beginning of Year | | 76828.82 |
| 174819.98 | AVAILABLE FOR APPROPRIATION | | 84136.88 |
| 4793.16 | Transfer to Library Fund | 6420.64 | |
| 93198.00 | Payment for Provision of Library Facilities | 4409.00 | |
| 97991.16 | | | 10829.64 |
| 76828.82 | ACCUMULATED FUNDS - Current Year | | 73307.24 |

FUNDS STATEMENT FOR THE YEAR ENDED 31ST DECEMBER 1978

| | 1977 $ | 1977 $ | 1978 $ | 1978 $ |
|---|---|---|---|---|
| SOURCE OF FUNDS | | | | |
| Operating deficit for the year | (420) | | - | |
| Add: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | 708 | | - | |
| Provision of doubtful debts | 1174 | | - | |
| Funds derived from operations | | 1462 | | - |
| Donations and interest to library fund | | 4793 | | 6420 |
| Withdrawal of investments | | 600 | | - |
| Trust fund income | | 1194 | | 1224 |
| Reduction in working funds | | - | | 2875 |
| Life Membership Subscriptions | | 34 | | 90 |
| Loan to associated company repaid | | 92500 | | - |
| Proceeds Estate Late Dr. J.F. Codrington | | 37504 | | 146 |
| | | $138087 | | $ 10755 |
| APPLICATION OF FUNDS | | | | |
| Operating deficit for the year | - | | 5521 | |
| Less: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | - | | 694 | |
| Provision for doubtful debts | - | | 730 | |
| Funds applied to operations | | - | | 4097 |
| Purchase of funiture and equipment | | 659 | | 998 |
| Reclassification of life members subscriptions in advance | | 8 | | 21 |
| Increase in investments | | 40000 | | 1000 |
| Trust fund expenses | | 649 | | 230 |
| Payment for provision of library facilities | | 93198 | | 4409 |
| Increase in working funds | | 3573 | | - |
| | | $138087 | | $ 10755 |

INCOME AND EXPENDITURE ACCOUNT

For the Year Ended 31 December 1978

| | | | | |
|---|---|---|---|---|
| | INCOME | | | |
| | Membership Subscriptions - | | | |
| 7286.00 | Ordinary | | | 6588.50 |
| | Membership Subscriptions - | | | |
| 6.17 | Life Members | | | 13.67 |
| 48.20 | Application Fees | | | 73.80 |
| 7340.37 | | | | 6675.97 |
| 3099.05 | Subscriptions to Journal | | | 3061.59 |
| 5500.00 | Government Subsidy | | | - |
| 15939.42 | Total Membership and Journal Income | | | 9737.56 |
| 2656.15 | Interest Received | | | 6101.29 |
| 2020.25 | Sale of Reprints | | | - |
| 1019.03 | Sale of Back Numbers | | | 578.09 |
| 192.30 | Sale of Other Publications | | | 119.70 |
| 2.00 | Donations - General | | | - |
| 59.13 | Annual Social Surplus | | | - |
| 620.17 | Summer School Surplus | | | 447.51 |
| 713.65 | Other Income | | | 136.40 |
| 23222.10 | | | | 17120.55 |
| | Less: EXPENSES | | | |
| 710.00 | Accountancy Fees | | 710.00 | |
| - | Advertising | | 54.00 | |
| - | Annual Social | | 213.10 | |
| 350.00 | Audit Fees | | 350.00 | |
| 100.00 | Branches of the Society | | - | |
| 90.00 | Cleaning | | 120.00 | |
| 708.00 | Depreciation | | 694.00 | |
| 425.29 | Electric Light and Power | | 237.07 | |
| 130.90 | Entertainment Expenses | | 156.39 | |
| 156.15 | Insurance | | 147.56 | |
| | Journal and Publication Costs | | | |
| | Printing - Current Year | | | |
| 4868.25 | Volume 111 | 4740.10 | | |
| 457.45 | Wrapping and Postage | 1194.85 | | |
| | | | 5934.95 | |
| 395.12 | Preparation of Index | | - | |
| - | Legal Costs | | 246.05 | |
| 747.38 | Library Purchases | | 865.77 | |
| 1637.80 | Library Relocation | | 13.50 | |
| 63.47 | Miscellaneous Expenses | | 721.22 | |
| 1197.18 | Postage | | 1150.15 | |
| 733.55 | Printing & Stationery - General | | 716.53 | |
| 1173.76 | Provision for Doubtful Debts | | 729.96 | |
| 2457.84 | Rent | | 2932.22 | |
| 130.64 | Repairs and Maintenance | | 71.35 | |
| - | Reprints - Loss on Sale | | 245.75 | |
| 5913.59 | Salaries | | 5449.33 | |
| 882.56 | Secretarial Services | | 659.49 | |
| 312.54 | Telephone | | 222.85 | |
| 23641.47 | | | | 22641.24 |
| 419.37 | DEFICIT for the year | | | 5520.69 |

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*Abstract.* A brief but fully informative abstract must be provided.

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# Contents

## VOLUME 112, PART 1



## VOLUME 112, PART 2




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# THE ROYAL SOCIETY OF NEW SOUTH WALES



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# JOURNAL AND PROCEEDINGS

# OF THE

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VOLUME 112

PART 3

1979

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## VOLUME 112, PART 3

Journal and Proceedings, Royal Society of New South Wales, Vol. 112, pp. 93-99, 1979

# Analysis of a Chiropractor's Data

GEOFFREY K. ALDIS AND JAMES M. HILL

ABSTRACT. Data from a chiropractor is studied with the view to obtaining a mathematical model of the alteration in the position of the atlas bone due to adjustment. The particular chiropractor believes that the patient's illness, for example low back pain, is primarily due to misalignments of the atlas bone, which he attempts to correct by applying a mechanically produced force. We find that there is considerable variation in the response of individual patients, indicating that a 'population' model is not applicable. In attempting to restore the atlas bone to its 'normal' position the chiropractor takes 'before' and 'after' X-rays, from which the displacements of the bone due to the applied force are measured. Statistically significant differences in before and after adjustment measurements are demonstrated both for the total sample and also when the sample is broken down into age, sex and adjustment type categories. It was found that there was not a transition from small misplacements of the atlas in the young to larger misplacements in the old.

## INTRODUCTION

Chiropractic therapy has never been accepted by the medical profession. This is partly due to its original association with mystical philosophy and also to the lack of scientific evidence to support its theories and its claims to effectiveness. In spite of this, chiropractors enjoy widespread support amongst the community. Studies (see Webb, 1977, page 49) indicate that many people seek chiropractic treatment and obtain relief after dissatisfaction with conventional medical treatment. Rather than reflect badly on chiropractic or medicine, the above suggests that there is a need for objective research to assess the clinical value of spinal manipulation. The present paper is concerned with a description of a chiropractor's adjustment technique and a statistical analysis of his patients' records to examine the position of the uppermost neck vertebra (the atlas) before and after adjustment. In keeping with these aims, the study was not intended to confirm or disprove chiropractic theories as they relate to the health of the patient, but rather to examine the mechanical effectiveness of adjustment in displacing the atlas.

Both chiropractic and established medicine hold the view that excessively rubbing, stretching or compressing nerves will adversely affect the areas these nerves supply, for example skin, kidney or muscle. Basic to all chiropractic is the notion of the misalignment of vertebrae or 'subluxation'. To the chiropractor, a vertebra need only be displaced a degree or more from its 'normal orientation' to be regarded as a subluxation. The medical profession considers that small displacements of vertebrae do not contribute to ill-health, but chiropractors regard them as the basic cause. Accordingly, chiropractors will attempt to restore the bones to their correct positions, while the medical profession will not.

This study was prompted by a chiropractor, who in attempting to improve his adjustment technique, approached us to consider the possibility of obtaining a mathematical model of his particular method. The adjustment technique is adapted from that originally proposed by Pettibon, 1968. It is not used by the majority of Australian chiropractors, and therefore our results are not readily extendible to include them. However, the overriding importance of this chiropractor's therapy is that it uses X-rays and employs a constant mechanically-produced adjusting force. These enable numerical values for vertebral displacements to be obtained, and unlike manual adjustments, enable an adjustment to be repeated almost exactly. In the following section we give a full description of the therapy. Briefly, three angular displacements of the atlas bone from 'normality' are measured from X-rays of the head and neck. A constant mechanically produced force is then applied to the temporal bone of the skull in an attempt to reduce the angular displacements. A second set of X-rays is then taken in order to measure the new angular displacements of the atlas. The displacement of the atlas due to the applied force can be calculated from this data.

Originally we proposed a deterministic force-displacement model, relating the displacement of the atlas caused by adjustment to the direction of the applied force. We found, however, that there is considerable variation in the response of different individuals to the applied force. This precluded the possibility of obtaining a single model applicable to more than one individual. Due to the random nature of the response we were led to a statistical analysis of the data. This is given in the fourth section. It should be borne in mind that the value of our statistical analysis is dependent on the quality of the data used. A discussion of the data is given in the third section. To the authors' knowledge, no analysis of chiropractors' data has appeared in the literature previously. From the statistical analysis we find evidence that the chiropractor reduces atlas misalignments at the population level. We also find that in the mean, older people (age 50 and above) do not have much larger total misplacements than

young people (age less than 30). We also find that the response to adjustment is uniform across the categories male/female and age less than 30/age 30 to 50/age 50 and older. We remark that in the following sections we have deliberately avoided strict anatomical terminology wherever there is no ambiguity in doing so. For instance, we will refer to the lateral tip of the transverse process of the atlas simply as the 'atlas tip' to improve readability.

DESCRIPTION OF THERAPY

The chiropractor's therapy is based on the assumption that subluxation of the atlas is the primary cause of the misalignment of the rest of the spine, and consequently contributes to all illness. For example, the chiropractor treats lower back pain not associated with a 'slipped' disc by adjustment of the atlas. This is a departure from conventional chiropractic practice which tends to adjust the spine near the point of discomfort. The chiropractor believes that if the atlas can be 'correctly' aligned with respect to the skull, then the rest of the spine will tend to reorganise itself into a normal configuration.

Three X-rays of the head and neck are taken. The first is taken from the side and is used to determine the position of the so-called S-line, along which the second X-ray (rear view) is taken (see Figs. 1a and 1b). For details of the S-line and other chiropractor terms the reader is referred to Pettibon, 1968. The third X-ray is taken along a line perpendicular to the S-line (see Figs. 2a and 2b). This view is the view obtained by looking along the arrowed line in Fig. 2a. In terms of their influence on the well-being of the patient, the chiropractor considers the three most important angles are in order:

(i) atlas laterality,
(When viewed from behind, the normal atlas lies along a line perpendicular to a mid-skull line. (see Fig. 1b). Atlas laterality is a measure of how far from 'horizontal' the atlas lies.)

(ii) lower angle,
(This angle is a measure of the amount to which the vertebrae below the atlas are out of line with the atlas (see Fig. 1b). A line is drawn through the centre of the second and third vertebral bodies. The lower angle is the deviation of this line from the perpendicular to the atlas plane line.)

(iii) atlas rotation,
(Ideally a line drawn through both lateral tips of the atlas should lie perpendicular to the skull midline (see Fig. 2b). Atlas rotation is a measure of how far the atlas is rotated from this position. Atlas rotation is measured on the side of atlas laterality.)

The case shown in Figs. 1 and 2 has atlas laterality left 2° and atlas rotation left posterior 2°.

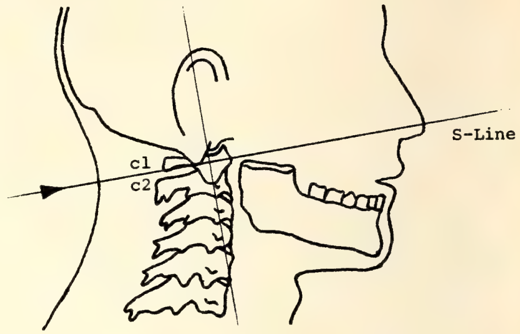


Fig. 1a. Lateral view of the neck, c1 is the atlas and c2 is the axis. (The view obtained by the rear X-ray is that seen along the S-line in the direction of the arrow.)

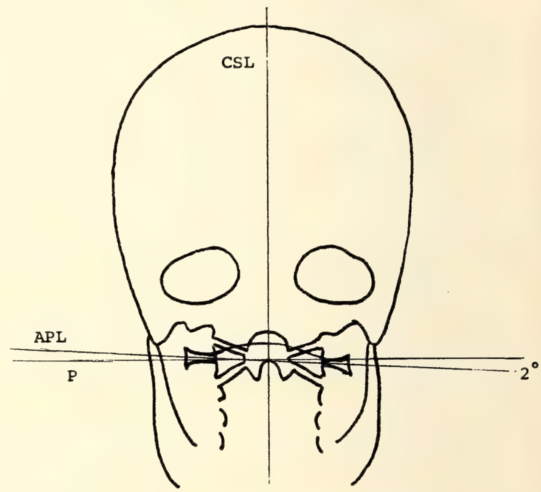


Fig. 1b. Rear X-ray showing an atlas laterality of left 2 degrees. (CSL is centre skull line, APL is atlas plane line and P is perpendicular to CSL.)

The tips of the atlas are convenient lever arms for displacing the upper neck vertebrae. The chiropractor differs from other chiropractors in the manner in which he applies the adjusting force. Firstly, instead of manipulating the atlas directly with his fingers, he uses a mechanically produced force. Secondly, instead of applying the force directly onto the tip of the atlas, he applies the force onto the temporal bone. The skull is struck slightly superior to the atlas tip, and either slightly anterior or posterior to the tip. Force is transmitted through the joint between the skull and atlas and some passes through muscle and soft tissue directly onto the tip. One reason why the chiropractor prefers this method is that in some patients the bony mastoid process (behind the ear) is

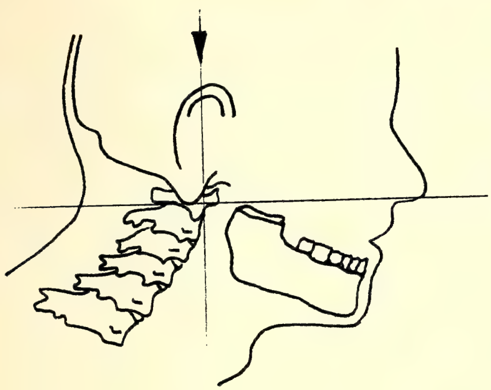

Fig. 2a. Lateral view of the neck. (The view obtained with the vertex X-ray is that seen along a line perpendicular to the S-line in the direction of the arrow.)

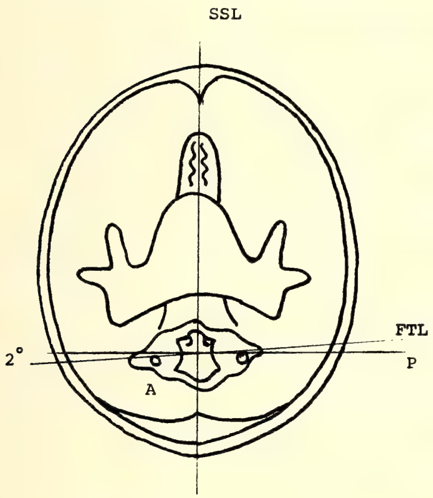


Fig. 2b. Vertex X-ray showing a left posterior atlas rotation of 2 degrees. (SSL is sagittal skull line, FTL is foraminal transverse line, P is perpendicular to SSL and A is atlas.)

particularly large and blocks direct access to the tip of the atlas. Another reason is that the shape of the joints between the skull and the atlas suggests that a force directed from above moves the atlas more efficiently.

If a person has a left (right) atlas laterality then the adjusting force is applied to the left (right) side of the skull. The adjustment is called a left (right) adjustment. If the atlas tip on the side of laterality is misplaced anteriorly, then the adjusting force is applied slightly anterior to the tip and directed backwards. The reverse applies for posterior misplacements. In addition to being anterior or posterior, an adjustment is either 'into the angles' or 'against the angles'. An 'into' adjustment is indicated if the atlas laterality and lower angle are both directed to the same side. An 'against' adjustment is performed if the atlas laterality and lower angle are directed towards opposite sides.

In setting the patient up for adjustment, the chiropractor instructs the patient to lie on his side on a movable couch, with his head on its side on a padded block. The side of the head for adjustment faces upward. The set up for 'against' and 'into' adjustments is slightly different, but in both cases the weight of the upper body is supported by the head and shoulder, with the length of the neck suspended above the couch.

An important reference line is the 'adjusting line'. It is noted on the lateral X-ray where this line crosses surface features of the face and side of the head, such as the outline of the nose, lips, ear, etc. The position of this line varies between patients and between different types of adjustments. Before adjustment the adjusting line is marked across the side of the patient's head with a skin pencil. The adjusting couch, with the patient correctly set up on it, is moved into position so that the adjusting line is in line with a reference line on the adjusting apparatus. The couch is then secured in this position.

The adjusting tool is a thin metal arm which may be directed at the skull from any angle. The arm is connected to the main framework of the adjusting apparatus, and may be raised and lowered, and moved left or right on threaded drives. The metal arm is spring-loaded, able to be cocked and released manually. The direction of the metal arm is set according to the chiropractor's experience from past adjustments. The metal contact point is then positioned over a point on the skull. The arm is continually cocked and released as it is gradually lowered onto the skull. The chiropractor feels the skull to determine when the arm first makes contact. After contact has been made once and another light contact made as the arm is backed off slightly, the adjustment is completed and the arm is fully backed off.

Another set of X-rays is taken immediately after the first adjustment. These are taken as a check on how effective the adjustment has been and to give information for future adjustments. The patient is only expected to maintain the corrected neck alignment for a relatively short length of time (3 days) and is advised to return for further adjustments until he can 'hold' the adjustment for several weeks. At these further adjustments X-rays are not usually taken.

## QUALITY OF DATA

Data was collected from a random sample of 140 new patients' records. These covered approximately an 18 month period. The values of the angles atlas laterality, lower angle and atlas rotation both before and after the first adjustment were collected. In addition, the type of adjustment, adjusting angle, and the direction of the adjusting force were collected for each patient. Ages at the time of the first X-ray for 122 of the patients were recorded, as were the sexes of 128. The angles

were measured by the chiropractor with a protractor having a half degree marking separation. Angles were measured to the nearest quarter of a degree with an error of plus or minus a quarter.

Several points should be made about the accuracy of the data. Firstly, there is no guarantee that the measurer (the chiropractor) is an unbiased observer. Secondly, there is variation between individuals in the location of anatomical landmarks used for measuring the angles. Thirdly, some anatomical structures have indistinct outlines or are blunt structures in X-ray views. Fourthly, while the X-ray set-up procedure is well-defined, it cannot guarantee exact results.

These points make it difficult for the authors to assess the true accuracy of the measurements. Nevertheless, in the authors' opinions, the data is sufficiently accurate to warrant a cautious statistical treatment, especially since the data collected is probably the best available from chiropractors in Australia at the moment. The authors would have preferred to substitute a correctly designed experiment for the collection of patients records, but the X-ray programme involved would have made funding prohibitive in an introductory study such as the present one.

STATISTICAL ANALYSIS OF DATA

Patients' records were examined under the categories total sample, males, females, age 0 to 29 years, age 30 to 49, age 50 and over, 'against' and 'into' adjustments. To examine the distributions of the neck angles in the different categories two approaches were considered. The first was to examine the mean positions of the three neck angles and associated variances both prior to and after adjustment. Values obtained are given in Table 1 (atlas laterality), Table 2 (lower angle) and Table 3 (atlas rotation). Negative values denote left-handed angles.

The results of F and t-tests are also shown in the tables. For each category and angle an F test tested the null hypothesis:

$$\text{Variance after adjustment} \geqslant \text{Variance before adjustment},$$

at the 0.05 level of significance. The degrees of freedom in each case were N-1, N-1, where N is the number in the category. For each category and angle, t-tests tested the null hypothesis:

$$|\text{Mean after adjustment}| \geqslant |\text{Mean before adjustment}|,$$

at the 0.05 level of significance. The degrees of freedom in each case were 2N-2, where N is the number in the category.

All cases in which the null hypothesis was rejected are denoted by an asterisk next to the calculated values of F or t. In the case of t-tests this indicates a significant improvement in the angle from adjustment at the population level. In the case of F-tests, a statistically significant result indicates a significantly smaller spread about the mean after adjustment.

In addition, frequency histograms of the three angles before and after adjustment for the total sample are given in Figs. 3a, 3b and 3c. We notice that all variances of the post-adjustment angle distributions are less than the corresponding pre-adjustment variances. This is well illustrated in Fig. 3b. All means except the "age less than 30 pre-adjustment lower angle" are between -1 and 1 degree but lower angle readings show a bias towards the negative or left-handed side. Also atlas rotations show a post-adjustment bias to negative or anterior rotations.

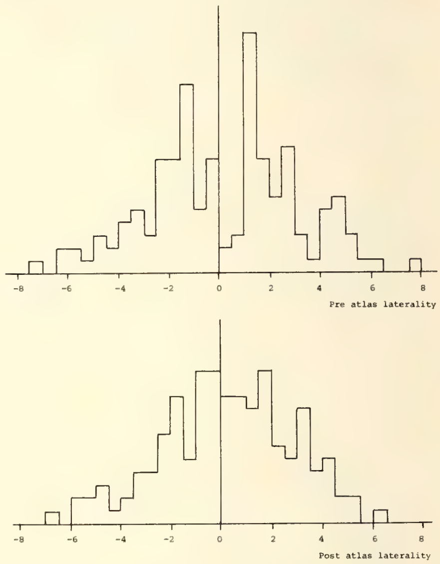


Fig. 3a. Frequency histograms for pre and post atlas laterality for 140 cases (angles in degrees).

The second approach to examining the angle distributions gave more information about the extent to which each patient's angles were misplaced from zero. A measure TDZ (total deviation from zero) was defined using the absolute value of each angle's misplacement from zero.

$$\text{TDZ} = |\text{Atlas Laterality}| + |\text{Atlas Rotation}| + 0.5|\text{Lower Angle}|.$$

The range of lower angle readings was approximately twice that of the other two angles, hence the 0.5 factor. Mean TDZ values and variances were calculated for the sample categories and F and t-tests were performed in the manner previously described. Results are shown in Table 4. We notice that all mean TDZ values are reduced by adjustment indicating that the chiropractor has achieved a nett correction. In all but two categories, reductions were statistically significant. Also, all but one of the variances are reduced. The female means are fractionally higher than the male means and the female variances are quite high compared with the males. The 'age 50 and over' group shows larger means than the other age groups. Also the 'age less than 30' group has higher mean TDZ values than the 'age 30 to 50' group. Against and into adjustments can be compared from entries in Tables 1, 2, 3 and 4. Both atlas laterality and atlas rotation appear to be reduced in a similar manner by both against

TABLE 1
ATLAS LATERALITY

| Category | Before Adjustment (Degrees) | | After Adjustment (Degrees) | | Number in Category | F (calculated) | t (calculated) |
|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | | | |
| Total sample | .04 | 8.68 | .09 | 6.75 | 140 | 1.28* | -.17 |
| Males | -.62 | 8.13 | -.38 | 6.52 | 66 | 1.25 | .49 |
| Females | .61 | 8.68 | .42 | 6.51 | 62 | 1.33 | .39 |
| Age less than 30 | -.33 | 9.20 | -.35 | 7.45 | 36 | 1.23 | -.02 |
| Age 30 to 50 | .56 | 7.70 | .51 | 4.70 | 52 | 1.64* | .10 |
| Age 50 and older | -.51 | 9.51 | -.26 | 8.30 | 34 | 1.15 | .34 |
| Against adjustments | .76 | 8.89 | .65 | 6.71 | 64 | 1.32 | .22 |
| Into adjustments | -.59 | 5.56 | -.37 | 5.36 | 61 | 1.04 | .52 |

TABLE 2
LOWER ANGLE

| Category | Before Adjustment (Degrees) | | After Adjustment (Degrees) | | Number in Category | F (calculated) | t (calculated) |
|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | | | |
| Total sample | -.76 | 14.06 | -.54 | 9.74 | 140 | 1.44* | .54 |
| Males | -.97 | 14.86 | -.70 | 11.41 | 66 | 1.30 | .43 |
| Females | -.66 | 13.61 | -.29 | 8.38 | 62 | 1.62* | .62 |
| Age less than 30 | -1.31 | 10.32 | -.51 | 7.34 | 36 | 1.41 | 1.12 |
| Age 30 to 50 | -.47 | 13.15 | -.88 | 9.15 | 52 | 1.44 | -.61 |
| Age 50 and older | -.88 | 20.49 | -.15 | 14.32 | 34 | 1.43 | .71 |
| Against adjustments | -.82 | 18.99 | -.14 | 11.68 | 64 | 1.63* | .97 |
| Into adjustments | -.91 | 11.94 | -.93 | 7.23 | 61 | 1.65* | -.04 |

TABLE 3
ATLAS ROTATION

| Category | Before Adjustment (Degrees) | | After Adjustment (Degrees) | | Number in Category | F (calculated) | t (calculated) |
|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | | | |
| Total sample | -.17 | 6.37 | -.27 | 5.15 | 140 | 1.24* | -.37 |
| Males | -.46 | 5.61 | -.48 | 4.64 | 66 | 1.21 | -.07 |
| Females | .09 | 6.97 | -.07 | 5.73 | 62 | 1.22 | .04 |
| Age less than 30 | -.48 | 6.06 | -.57 | 5.26 | 36 | 1.15 | -.16 |
| Age 30 to 50 | -.28 | 4.94 | -.26 | 4.25 | 52 | 1.16 | .06 |
| Age 50 and older | .15 | 8.12 | -.07 | 6.64 | 34 | 1.22 | .12 |
| Against adjustments | .32 | 6.57 | -.10 | 5.98 | 64 | 1.10 | .49 |
| Into adjustments | -.36 | 5.75 | -.26 | 4.47 | 61 | 1.29 | .24 |

TABLE 4
TOTAL DEVIATION FROM ZERO OF NECK ANGLES

| Category | Before Adjustment (Degrees) | | After Adjustment (Degrees) | | Number in Category | F (calculated) | t (calculated) |
|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | | | |
| Total sample | 6.02 | 6.33 | 5.13 | 5.63 | 140 | 1.12 | 3.01* |
| Males | 5.92 | 5.33 | 5.05 | 4.88 | 66 | 1.09 | 2.20* |
| Females | 6.11 | 7.57 | 5.21 | 6.42 | 62 | 1.18 | 1.88* |
| Age less than 30 | 5.97 | 6.41 | 5.12 | 6.76 | 36 | 0.95 | 1.39 |
| Age 30 to 50 | 5.49 | 5.81 | 4.64 | 4.43 | 52 | 1.31 | 1.90* |
| Age 50 and older | 6.88 | 6.07 | 5.94 | 5.57 | 34 | 1.09 | 1.59 |
| Against adjustments | 6.45 | 7.38 | 5.39 | 6.89 | 64 | 1.07 | 2.23* |
| Into adjustments | 5.56 | 4.61 | 4.74 | 4.16 | 61 | 1.11 | 2.08* |

* Null hypothesis rejected at 0.05 level of significance.

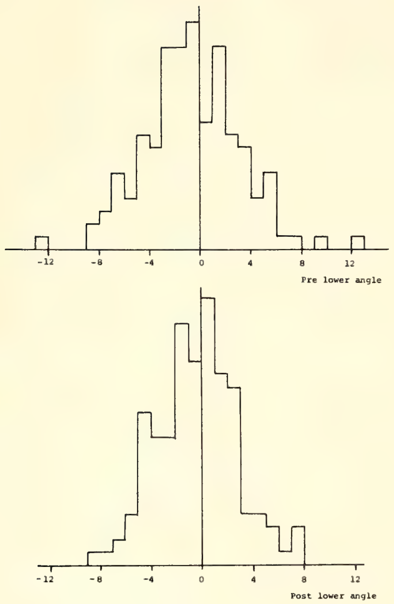


Fig. 3b. Frequency histograms for pre and post lower angle for 140 cases (angles in degrees).

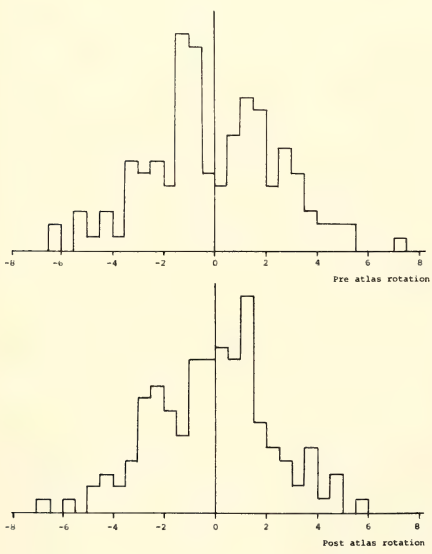


Fig. 3c. Frequency histograms for pre and post atlas rotation for 140 cases (angles in degrees).

and into adjustments. However, the against adjustment appears to be more effective than the into at reducing the lower angle. Table 4 shows that the TDZ is affected in a similar manner by both against and into adjustments.

The total sample data was examined with correlation coefficients to determine whether the displacement of an angle on adjustment was related to its initial position. Because of the expected symmetry of positive and negative initial positions, a correlation coefficient was calculated for both positive and negative segments of the initial position range. The results are shown in Table 5. None of the coefficients show a strong linear relationship between displacement and initial position, although lower angle shows some symmetry about zero in its response. Graphs of displacement against initial position for the age and sex categories reflected the lack of a strong linear relationship and did not suggest a non-linear relationship, but rather a random one.

CONCLUSIONS

Analysis of the data shows that while the chiropractor achieves a nett improvement in angles at the population level, individual responses to adjustment vary greatly. With the possible exception of the lower angle, displacement of an angle on adjustment appears to be unrelated to its initial position. These findings suggest that there is no simple predictive model which could be reliably used. Patient - specific information is obtained by studying the response to the first adjustment, and the chiropractor may well achieve more predictable results with further adjustments. Unfortunately, X-rays are not usually taken at further adjustments. As well as the statistically significant values of $t$ and $F$, evidence for differences between before and after values lies in the fact that the same patterns were evident in all divisions of data, either as the total sample, the two sexes, or the three age-groups. Variances were consistently smaller after adjustment and mean positions of angles and TDZ (total deviation from zero) were consistently closer to zero after adjustment.

The authors expected that the gradual tightening of ligaments and subsequently decreased freedom of movement of joints with age would have been reflected in the response to adjustment. It was therefore surprising to find that the response to adjustment of all age groups was similar. The TDZ values before and after adjustments indicated that the '50 and older' age group had slightly larger initial and final misplacements than the other two age groups. However there was not a transition from small misplacements in the young to large misplacements in the old.

An interesting point arising from the frequency histograms of atlas laterality (Fig. 3a) is that the distribution prior to adjustment appears bimodal, and after adjustment appears more like the Gaussian or Normal distribution. The chiropractor regards atlas laterality as the atlas angle most important to the patient's health. Data from a healthy population could resolve the question of whether the atlas laterality distribution is normally skew and thereby whether it is a likely factor contributing to the health of the patient.

TABLE 5

CORRELATION COEFFICIENTS $\rho_{xy}$ OF DISPLACEMENT (Y) AGAINST INITIAL POSITION (X) FOR THE TOTAL SAMPLE

| | $\rho^{+}_{xy}$ of Positive Initial Position | Number Data Points for $\rho^{+}_{xy}$ | $\rho^{-}_{xy}$ of Negative Initial Position | Number Data Points for $\rho^{-}_{xy}$ |
|---|---|---|---|---|
| Atlas Laterality | .25 | 70 | -.05 | 70 |
| Lower Angle | .20 | 57 | -.35 | 83 |
| Atlas Rotation | .24 | 66 | .12 | 74 |

Further work could include examination of neck angle distributions of a healthy sample, and of individuals over a period of time without adjustment. However, the transition from an introductory survey of patients' records to the implementation of an experimentally designed X-ray investigation would require a considerable funding commitment.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the chiropractor who prompted this investigation. Evidently in making all his data freely available to us he invited the possibility of severe criticism. This research was supported by a University Research Grant.

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# Astrometric Determination of Membership Probabilities in Galactic Clusters

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ABSTRACT. Photographic measurement of the relative proper motions in the region of a galactic cluster are used to assign a probability of membership to each star. The probability of membership is dependent upon the weights given to the results and the determination of the distribution parameters. A more objective method is given for both.

## INTRODUCTION

At Sydney Observatory, the relative proper motions of stars in the region of galactic clusters has been obtained for the following clusters:- NGC 6025, NGC 3532, NGC 2516, NGC 4103. At present we are continuing with NGC 2669 together with IC 2391 and hope to go on to NGC 5662 and NGC 6087. The procedure used involves matching the plates taken with the 33cm standard astrograph (scale 1' = 1 mm) approximately 80 years ago, with plates taken with the same lens more recently. This gives the motion of the stars over a time interval of about 80 years. The plates are measured in a Grubb-Parsons photoelectric measuring machine in both direct and reverse positions. The reverse positions are converted into direct measures using plate constants and the average is recorded.

If $x_1$, $y_1$ are the coordinates of a star on the new plate and $x_2$, $y_2$ its coordinates on the old plate and there has been an annual proper motion of $\mu$ in x and $\nu$ in y over t years, then we can write:-

$$x_1 - x_2 = \mu t + ax_1 + by_1 + c + dm$$

with a similar expression for $y_1 - y_2$ where m is the magnitude taken from either the Cape Photographic Catalogue or the Sydney Astrographic Catalogue.

A least squares solution without the proper motion term is then calculated using all the stars measured on that plate pair. Those stars whose residuals exceed 25 microns are eliminated from the solution and a further least squares solution is sought of the remaining stars. This is repeated for successive limiting residuals of 10, 7.5 and 5 microns. The final standard deviation of the stars in the solution is usually approximately 2 microns i.e. 0".12. That is, the dispersion of the cluster stars together with the measuring errors amounts to approximately 0".12 per 80 years. The resultant proper motion plate constants are then used to give the proper motions relative to the mean motion of the cluster.

## THE WEIGHTS

Assigning a weight to each of the plate pairs subjectively, is not the best method. If the plate quality is low, then it should be obvious by the variance of its results from the average of all plate pairs. Therefore, an easy way of quantifying the accuracy of the measurement for a particular plate pair is to calculate the variance of the difference between the individual motion and the average motion, both in seconds of arc per century. This should be calculated when there are at least four plate pairs. The average of plate pairs excluding the one whose weight is being determined, could be used instead of the average of all plate pairs if so desired. For a reasonable number of plate pairs this makes very little difference to the weights.

## THE PROBABILITIES

A method for computing membership probabilities has been devised by Sanders (1971). This involves representing the observed proper motions as two overlapping bivariate gaussian frequency functions (one circular for the cluster and one elliptical for the field.) The frequency function is given by the following equation;

$$\begin{aligned}\Phi(\mu_i,\nu_i) &= \Phi^f + \Phi^c \\ &= \frac{N_f}{2\pi\Sigma_x\Sigma_y} \exp\left(-\frac{1}{2}\left(\frac{\{\mu_i - X_f\}^2}{\Sigma_x^2} + \frac{\{\nu_i - Y_f\}^2}{\Sigma_y^2}\right)\right) + \frac{N_c}{2\pi\sigma_c^2} \exp\left(-\frac{1}{2}\left(\frac{\mu_i^2 + \nu_i^2}{\sigma_c^2}\right)\right) \\ &= \frac{N_f}{2\pi\Sigma_x\Sigma_y}\,\alpha + \frac{N_c}{2\pi\sigma_c^2}\,\beta\end{aligned}$$

where I have taken the cluster centre to be the origin, which it should be from the calculation of the least squares solution $\sigma_c$ is the dispersion of the cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars; $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions; $\mu_i$, $\nu_i$ the centennial proper motion for the ith star. All the parameters as well as the coordinates of the motion are defined in the rotated coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions. The method of maximum likelihood gives the following nonlinear equations of condition.

$$N \;:\; \sum \frac{1}{\Phi}\left(\frac{\alpha}{\Sigma_x\Sigma_y} - \frac{\beta}{\sigma_c^2}\right) = 0$$

$$X_f \;:\; \sum \frac{\alpha}{\Phi}\left(\mu_i - X_f\right) = 0$$

$$Y_f \;:\; \sum \frac{\alpha}{\Phi}\left(\nu_i - Y_f\right) = 0$$

$$\Sigma_x \;:\; \sum \frac{\alpha}{\Phi}\left(\frac{\{\mu_i - X_f\}^2}{\Sigma_x^2} - 1\right) = 0$$

$$\Sigma_y \;:\; \sum \frac{\alpha}{\Phi}\left(\frac{\{\nu_i - Y_f\}^2}{\Sigma_y^2} - 1\right) = 0$$

$$\sigma_c \;:\; \sum \frac{\beta}{\Phi}\left(\frac{\mu_i^2 + \nu_i^2}{\sigma_c^2} - 2\right) = 0$$

The summation being over the known total population $(N_c + N_f)$.

It is also desirable to include an additional equation that will enable the calculation of the rotation angle $\theta$. Contrary to W.L. Sanders, this equation does not result in "undesirable complications". The equation is:

$$\theta \;:\; \sum \frac{\alpha}{\Phi}\left(\frac{\nu_i\{\mu_i - X_f\}}{\Sigma_x^2} - \frac{\mu_i\{\nu_i - Y_f\}}{\Sigma_y^2}\right) = 0$$

The previous seven equations are solved by assuming initial values, then calculating the value of the associated parameter of each equation in turn. After several iterations the parameters converged in all cases studied. Thus, the probability of membership is determined for the ith star as:

$$P_i^c = \frac{\Phi_i^c}{\Phi_i^c + \Phi_i^f}$$

One aspect has so far been neglected, and that is if the field star distribution is not a normal one. Local motion and differential galactic rotation cause some stars to depart from the normal distribution. These should first be removed from the calculation of parameters in order to satisfy the model. Without the correct amount of pruning it is found that the proper motions do not fit the calculated distribution given by the statistical parameters. I have used a chi-squared test to determine whether the parameters are actually fitting a binormal distribution. This involves dividing both the field and cluster stars into seven parts according to the number of standard deviations they are away from the centre of the field and cluster motion. Then the probability of either field or cluster membership are summed for all the stars with motions in each particular range. These numbers can then be compared with the expected numbers for a normal distribution. For example, the solution for NGC 4103 after already eliminating two field stars, gives the results in Table 1.

Thus, the value of $X^2$ for the field is 17.49 and for the cluster is 18.23. There are six degrees of freedom so there is only a 1% chance that if we reject the solution it was the correct one for either cluster or field. Hence pruning of the stars is continued, choosing those stars which are the largest number of standard deviations away from the field centre. In this case the two stars which produced the numbers denoted by "*". Attention is drawn to the fact that these numbers are not integers, since they represent the sum of the probabilities that stars in this range are field stars. Pruning in this example was continued until 15 stars were eliminated and the values of $X^2$ were 2.22 for the field and 0.55 for the cluster.

TABLE 1 - $\chi^2$ TEST

| RANGE OF STANDARD DEVIATIONS | RANGE OF $\alpha$ OR $\beta$ | EXPECTED PERCENTAGE | FIELD EXPECTED NUMBER | FIELD ACTUAL NUMBER | CLUSTER EXPECTED NUMBER | CLUSTER ACTUAL NUMBER |
|---|---|---|---|---|---|---|
| 0.0 - 1.0 | 1.00000 - 0.60653 | 39.347 | 11.422 | 15.023 | 55.075 | 74.158 |
| 1.0 - 1.5 | 0.60653 - 0.32465 | 28.188 | 8.183 | 8.006 | 39.455 | 22.648 |
| 1.5 - 2.0 | 0.32465 - 0.13534 | 18.931 | 5.495 | 1.000 | 26.498 | 20.176 |
| 2.0 - 2.5 | 0.13534 - 0.04394 | 9.140 | 2.653 | 3.000 | 12.793 | 12.802 |
| 2.5 - 3.0 | 0.04394 - 0.01111 | 3.283 | 0.953 | 0.000 | 4.595 | 7.991 |
| 3.0 - 3.5 | 0.01111 - 0.00219 | 0.892 | 0.259 | 1.000* | 1.249 | 1.882 |
| 3.5 - $\infty$ | 0.00219 - 0.00000 | 0.219 | 0.064 | 1.000* | 0.306 | 0.414 |
| | | 100.000 | 29.029 | 29.029 | 139.971 | 139.971 |

$$\chi^2 = \sum \frac{(\text{ACTUAL-EXPECTED})^2}{\text{EXPECTED}}$$

Table 2 illustrates how $X^2$ varies as we eliminate field stars around the chosen value of 15. From Table 2 it is apparent that 15 stars need to be rejected in order to best satisfy the original model.

TABLE 2 - EFFECT OF PRUNING

| NUMBER ELIMINATED | VALUE OF $X^2$ FIELD | VALUE OF $X^2$ CLUSTER | ACTUAL-EXPECTED NO. IN 1 S.D. FIELD | ACTUAL-EXPECTED NO. IN 1 S.D. CLUSTER |
|---|---|---|---|---|
| 2 | 17.49 | 18.23 | 3.60 | 19.10 |
| 3 | 4.38 | 13.64 | 2.55 | 14.64 |
| 6 | 1.75 | 8.18 | -0.87 | 11.48 |
| 8 | 1.68 | 7.22 | 0.35 | 11.23 |
| 13 | 1.09 | 5.58 | -0.60 | 3.23 |
| 14 | 6.42 | 1.24 | -2.10 | 0.43 |
| 15 | 2.22 | 0.55 | -3.40 | -0.41 |
| 16 | 2.79 | 2.78 | -1.52 | -3.12 |
| 17 | 2.67 | 2.06 | -1.27 | -2.67 |

The inaccuracy of the membership probabilities must at least exceed the difference in probabilities between solutions obtained by pruning one more or one less field star. Table 3 shows the change in individual star membership probabilities between the solutions obtained from eliminating one more or one less than the chosen rejection number of 15. The difference is greatest for stars with probabilities of one half of the maximum probability since these stars are on the wings of the cluster gaussian distribution and are thus very sensitive to the value of $\sigma_c$. However, the effect of pruning one or two stars incorrectly is less than the change in probability caused by varying a star's motion by the standard error of its motion. The standard error of an individual stars motion is on the average only marginally smaller than the value of the cluster dispersion for even the nearest clusters, indicating that the majority of the cluster dispersion is due to measuring errors. For NGC 4103 the standard error of the individual motions averaged at $0\overset{''}{.}076$/century while the cluster dispersion after 15 stars were rejected was $0\overset{''}{.}103$/century. The last column of Table 3 shows how the probability is affected by increasing the motion of each star by the cluster dispersion $\sigma_c$. The probabilities are not quite in error by this amount but it does show a need for caution when applying the membership probabilities.

## CONCLUSION

The effect of local motion and differential galactic rotation can be reduced by appropriate pruning of stars from the field, thereby increasing the significance of individual membership probabilities. In reality, a star is either 100% bound by the clusters gravitational field or not bound at all, so our probabilities of membership are only ever as good as the measurements of the motion, position and photometry of the stars.

TABLE 3 - VARIATION OF PROBABILITIES

| PROBABILITY RANGE | NUMBER OF STARS | AVERANGE CHANGE IN PROBABILITY REJECTED 15 CF. REJECTED 14 | REJECTED 16 | CHANGE MOTION BY $\sigma_c$ |
|---|---|---|---|---|
| 85-90 | 3 | 2.8 | 1.8 | 4.4 |
| 80-85 | 23 | 3.6 | 2.3 | 7.4 |
| 75-80 | 20 | 5.1 | 3.5 | 16.9 |
| 70-75 | 17 | 7.1 | 5.1 | 16.8 |
| 65-70 | 4 | 9.6 | 6.4 | 19.7 |
| 60-65 | 7 | 9.5 | 6.7 | 29.0 |
| 55-60 | 4 | 10.8 | 7.2 | 29.1 |
| 50-55 | 4 | 11.8 | 8.0 | 21.8 |
| 45-50 | 3 | 13.6 | 8.6 | 24.8 |
| 40-45 | 3 | 15.4 | 9.0 | 22.9 |
| 35-40 | 2 | 16.9 | 10.1 | 15.8 |
| 30-35 | 4 | 16.0 | 8.5 | 27.1 |
| 25-30 | 2 | 15.9 | 7.9 | 28.9 |
| 20-25 | 2 | 14.8 | 7.6 | 16.6 |
| 15-20 | 5 | 14.3 | 6.1 | 17.8 |
| 10-15 | 5 | 13.4 | 5.2 | 27.6 |
| 5-10 | 5 | 11.4 | 3.9 | 6.8 |
| 0-5 | 43 | 2.1 | 0.6 | 2.0 |

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# Proper Motions in the Region of the Galactic Clusters NGC 2669 and IC 2391

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ABSTRACT. Relative proper motions of stars in the region of the galactic cluster NGC 2669 are determined with the aim of identifying stars which are non-members. The relative proper motions have an average standard error of 0".09/century and reveal 87 likely members and 139 likely non-members. Likely members of IC 2391 are also identified.

## INTRODUCTION

The open cluster NGC 2669 (R.A. = $8^h\ 43^m.4$, Dec. = $-52^\circ\ 47'$; 1950) lies in the same field as the cluster IC 2391 (R.A. = $8^h\ 41^m.4$, Dec. = $-53^\circ\ 00'$; 1950). The latter has been studied photometrically by Lyngå (1961, 1966). The present investigation seeks to identify from their proper motions, those stars that are not members of NGC 2669.

## THE PLATES

The plates were taken with the 33cm standard astrograph (scale 1' = 1 mm) as follows:

| | Plate No. | Date Taken | Exposure | Plate Pair |
|---|---|---|---|---|
| 1 | 791s | 1893 Mar. 12 | 6 m | 1 |
| 2 | 791s | 1893 Mar. 12 | 3 m | 2 |
| 3 | 2333s | 1895 Mar. 4 | 1½ m | 3 |
| 4 | 2333s | 1895 Mar. 4 | ¾ m | 4 |
| 5 | 2334s | 1895 Mar. 4 | 1½ m | 5 |
| 6 | 2334s | 1895 Mar. 4 | ¾ m | 6 |
| 7 | 2354s | 1895 Mar. 25 | 30 m | 7 |
| 8 | 3169s | 1896 Dec. 31 | 30 m | 8 |
| 9 | 134RH | 1900 Feb. 6 | 3 m | 9 |
| 10 | 134RH | 1900 Feb. 6 | 1½ m | 10 |
| 11 | N207 | 1920 Mar. 13 | 4 m | 11 |
| 12 | N207 | 1920 Mar. 13 | 2 m | 12 |
| 13 | N764 | 1923 Apr. 19 | 4 m | 13 |
| 14 | N764 | 1923 Apr. 19 | 2 m | 14 |
| 15 | 7793Sa | 1979 Mar. 5 | 20 m | 8 |
| 16 | 7798Sa | 1979 Mar. 20 | 10 m | 10 |
| 17 | 7799Sa | 1979 Mar. 20 | 10 m | 13 |
| 18 | 7803Sa | 1979 Mar. 21 | 20 m | 7 |
| 19 | 7804Sa | 1979 Mar. 21 | 5 m | 14 |
| 20 | 7805Sa | 1979 Mar. 21 | 10 m | 2 |
| 21 | 7806Sa | 1979 Mar. 25 | 17 m | 1 |
| 22 | 7807Sa | 1979 Mar. 25 | 20 m | 9 |
| 23 | 7808Sa | 1979 Mar. 26 | 15 m | 5 |
| 24 | 7809Sa | 1979 Mar. 26 | 10 m | 6 |
| 25 | 7810Sa | 1979 Mar. 26 | 5 m | 12 |
| 26 | 7818Sa | 1979 Mar. 31 | 10 m | 3 |
| 27 | 7819Sa | 1979 Mar. 31 | 5 m | 4 |
| 28 | 7820Sa | 1979 Mar. 31 | 10 m | 11 |

Plate pairs 3 and 4 were centred at R.A. $8^h\ 36^m$ Dec. $-52^\circ\ 00'$ (1900). Plate pairs 5, 6, 11 and 12 were centred at R.A. $8^h\ 48^m$. Dec. $-52^\circ\ 00'$ (1900). All other plate pairs were centred at R.A. $8^h\ 42^m$ Dec. $-53^\circ\ 00'$ (1900).

## MEASUREMENT

The plates were each measured in a Grubb-Parsons photoelectric measuring machine in both direct and reverse positions. The reverse positions were converted into direct measures using plate constants and the average was recorded. All stars measured were selected from the published coordinates in the Astrographic Catalogue (Sydney Observatory 1954, plate N764.) The plates were measured by Mrs. J. Close, Miss D. Teale, Miss J. Westaway and Mr. D. King.

## REDUCTIONS AND PROBABILITIES

The method of reduction and calculation of membership probabilities is described in a previous paper appearing in this issue of the journal. The distribution parameters in arc sec./century after eliminating 19 stars to obtain the best fit were

$\theta = 47^\circ.19 \quad N_f = 120 \quad X_f = -0.438 \quad \Sigma_x = 1.373$

$\sigma_c = 0.209 \quad N_c = 87 \quad Y_f = -0.074 \quad \Sigma_y = 0.399$

$\theta$ is the rotation angle of the observed proper motions ($+\mu$ to $+\nu$) into a new coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions. All the other parameters are defined in this new coordinate system. $\sigma_c$ is the dispersion of the cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars. $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions.

The standard errors for individual stars have been grouped by their magnitudes, and the mean of the standard errors $\sigma_\mu$, $\sigma_\nu$ determined for different ranges are as follows:-

| Magnitude | $\sigma_\mu$ | $\sigma_\nu$ | No. of stars |
|---|---|---|---|
| | (Unit 0".01/cent) | | |
| 10.5 - 10.9 | 8.50 | 9.42 | 12 |
| 10.0 - 10.4 | 8.99 | 8.55 | 145 |
| 9.5 - 9.9 | 8.41 | 7.47 | 41 |
| 9.0 - 9.4 | 9.00 | 9.00 | 12 |
| 6.2 - 8.9 | 10.38 | 9.00 | 16 |
| All | 8.96 | 8.45 | 226 |

An examination of the proper motions relative to the motion of NGC 2669 reveals a clustering of 39 stars within 0″.80/cent. of $\mu$ = -1″.40/cent. and $\nu$ = +1″.30/cent. From the magnitudes of these 39 stars it seems likely that these are members of the dispersed cluster IC 2391 which lies less than 300 parsecs away from us.

The absolute proper motion of the cluster NGC 2669 by comparison with 30 Cape Catalogue stars is -1.96 ± 0.26″/cent. in R.A. and + 0.50 ± 0.26″/cent. in Dec.

The observational data follows in table 1. The various columns are:-

No. The number from the Astrographic Catalogue, Sydney Section ($8^h$ $42^m$ -53° centre).
Mag. The magnitude of the star taken from either the Cape Photographic Catalogue or the Sydney Astrographic Catalogue.
R.A. Right ascension (1950), all prefixed by 8 hours.
Dec. Declination (1950).
CPD No. Prefixed by -52°.
V Photovisual magnitude from Mermilliod.
M No. Number as given in Mermilliod's Catalogue.
$\mu$,$\nu$ Centennial proper motion in units of 0″.01/cent. Motion of $\mu$ in R.A. and $\nu$ in Dec.
$\sigma_\mu$,$\sigma_\nu$ Standard errors of centennial proper motion in units of 0″.01/cent.
P Probability of membership in NGC 2669.
Notes
1 - V magnitude and M No. refer to NGC 2669. All other V magnitudes and M No's refer to IC 2391.
2 - Too bright for an accurate determination of proper motion. Radial velocity in the range +14 to +19 km/sec. consistent with membership of IC 2391.
3 - Proper motion consistent with membership of IC 2391.
6 - Not used in calculation of distribution parameters.
B - Spectroscopic binary or variable radial velocity.
D - Double star.

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TABLE 1

THE OBSERVATIONAL DATA

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 252 | 10.1 | 47 07 | -53 07 40 | 1679 | | | 5 | -37 | 9 | 11 | 69 | |
| 253 | 10.5 | 46 22 | -53 06 43 | | | | 50 | -43 | 14 | 14 | 8 | |
| 254 | 9.7 | 45 59 | -53 07 48 | 1670 | | | 84 | - 2 | 8 | 6 | 2 | |
| 255 | 10.3 | 45 44 | -53 08 45 | | | | 22 | 16 | 14 | 11 | 86 | |
| 256 | 9.7 | 45 15 | -53 08 23 | 1661 | | | 23 | -117 | 11 | 9 | 0 | |
| 257 | 10.2 | 43 32 | -53 06 55 | | | | 10 | 118 | 11 | 11 | 0 | |
| 258 | 10.1 | 43 30 | -53 07 06 | | | | -16 | 15 | 11 | 9 | 84 | |
| 259 | 10.5 | 43 03 | -53 07 34 | | | | 7 | -40 | 11 | 6 | 63 | |
| 260 | 10.1 | 42 51 | -53 09 46 | 1633 | | | -14 | 35 | 10 | 8 | 67 | |
| 261 | 10.3 | 42 15 | -53 09 33 | | | | 10 | -63 | 5 | 5 | 12 | |
| 261A | 10.3 | 42 07 | -53 09 18 | | | | -48 | 13 | 8 | 9 | 37 | |
| 261B | 10.3 | 42 03 | -53 08 21 | | | | -66 | -59 | 11 | 13 | 1 | |
| 262 | 10.2 | 41 36 | -53 10 21 | | | | 32 | -16 | 10 | 8 | 74 | |
| 263 | 10.3 | 41 28 | -53 08 56 | | | | -37 | 107 | 7 | 11 | 0 | |
| 264 | 9.5 | 39 59 | -53 07 10 | 1595 | 10.18 | 25 | 80 | -29 | 9 | 9 | 1 | |
| 265 | 10.4 | 39 09 | -53 07 28 | | | | 22 | 7 | 11 | 6 | 87 | |
| 266 | 10.3 | 38 59 | -53 07 50 | | | | -122 | 166 | 10 | 14 | 0 | 3 |
| 267 | 10.3 | 38 57 | -53 10 01 | | | | -297 | 135 | 8 | 11 | 0 | 6 |
| 268 | 9.5 | 38 10 | -53 08 18 | 1576 | 10.16 | 55 | 2 | - 2 | 8 | 9 | 91 | |
| 269 | 9.2 | 37 53 | -53 06 27 | 1574 | 9.38 | 12 | -34 | 10 | 10 | 9 | 69 | |
| 270 | 10.1 | 37 51 | -53 06 10 | 1573 | 11.57 | 59 | 8 | -33 | 9 | 8 | 74 | |
| 278 | 10.3 | 46 08 | -53 01 39 | | | | 22 | 1 | 13 | 11 | 87 | |
| 278A | 10.4 | 45 11 | -53 02 30 | | | | -12 | -14 | 8 | 10 | 87 | |
| 278B | 10.3 | 44 58 | -53 04 57 | | | | -95 | 63 | 15 | 5 | 0 | 3 |
| 279 | 10.4 | 44 23 | -53 01 51 | | | | -14 | -62 | 8 | 3 | 16 | |
| 280 | 10.3 | 43 48 | -53 03 03 | | | | 334 | -393 | 10 | 9 | 0 | 6 |
| 281 | 10.3 | 42 46 | -53 01 41 | | | | 31 | -131 | 8 | 14 | 0 | |
| 282 | 10.3 | 42 39 | -53 04 37 | | | | 6 | -29 | 4 | 12 | 79 | |
| 282A | 10.4 | 42 29 | -53 02 25 | | | | -49 | 30 | 6 | 9 | 17 | |
| 283 | 9.3 | 42 26 | -53 03 06 | 1631 | | | -173 | 138 | 9 | 7 | 0 | 3 |
| 284 | 10.1 | 41 33 | -53 04 16 | 1620 | | | -108 | 123 | 7 | 8 | 0 | 3 |
| 285 | 10.3 | 41 27 | -53 03 43 | | | | -31 | 4 | 6 | 5 | 76 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | μ | ν | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 286 | 10.3 | 41 17 | -53 02 37 | | | | -66 | - 2 | 5 | 5 | 10 | |
| 286A | 10.5 | 40 58 | -53 02 50 | | | | 69 | -244 | 3 | 6 | 0 | 6 |
| 287 | 10.4 | 40 57 | -53 03 50 | | | | -329 | 164 | 13 | 9 | 0 | 6 |
| 288 | 10.3 | 39 23 | -53 05 06 | | | | -144 | 133 | 7 | 15 | 0 | 3 |
| 289 | 7.0 | 38 34 | -53 04 58 | 1581 | 7.22 | 18 | 28 | -22 | 9 | 7 | 73 | B |
| 290 | 10.1 | 38 07 | -53 02 39 | | | | -13 | -90 | 6 | 6 | 0 | |
| 291 | 10.1 | 38 03 | -53 02 54 | | | | 23 | -41 | 10 | 11 | 47 | |
| 292 | 10.3 | 37 53 | -53 03 15 | | | | -162 | 61 | 15 | 7 | 0 | 3 |
| 293 | 10.2 | 36 53 | -53 00 47 | | | | -285 | 149 | 15 | 11 | 0 | 6 |
| 294 | 10.1 | 36 35 | -53 00 12 | 1559 | | | -23 | -33 | 9 | 10 | 68 | |
| 301 | 9.3 | 47 49 | -52 59 31 | 1687 | | | -39 | -128 | 9 | 7 | 0 | 6 |
| 302 | 9.9 | 47 31 | -52 59 57 | 1683 | | | 116 | 39 | 10 | 5 | 0 | 6 |
| 303 | 9.9 | 46 39 | -52 58 18 | 1677 | | | -17 | 0 | 9 | 8 | 87 | |
| 303A | 10.4 | 46 06 | -52 59 05 | | | | - 3 | 9 | 9 | 9 | 90 | |
| 304 | 9.9 | 45 40 | -52 56 53 | 1666 | | | 22 | 15 | 7 | 5 | 86 | |
| 304A | 10.3 | 44 55 | -53 00 47 | | | | -36 | 34 | 12 | 10 | 35 | |
| 305 | 10.3 | 44 49 | -52 57 46 | | | | -175 | 131 | 4 | 6 | 0 | 3 |
| 306 | 8.9 | 44 48 | -52 56 42 | 1648 | 9.11 | 47 | - 2 | -12 | 9 | 9 | 89 | D |
| 307 | 10.3 | 44 36 | -52 59 29 | | | | - 6 | 11 | 7 | 5 | 89 | |
| 308 | 10.3 | 44 24 | -52 57 24 | | | | 159 | -282 | 5 | 8 | 0 | 6 |
| 309 | 10.5 | 44 20 | -52 57 31 | | | | -137 | 84 | 5 | 13 | 0 | 3 |
| 310 | 10.3 | 44 04 | -52 59 02 | | | | 87 | 291 | 4 | 4 | 0 | 6 |
| 311 | 10.3 | 43 13 | -52 57 34 | | | | 27 | - 9 | 12 | 7 | 82 | |
| 312 | 9.9 | 41 53 | -52 57 12 | 1626 | 10.93 | 62 | 58 | -48 | 8 | 5 | 2 | |
| 313 | 9.7 | 41 45 | -52 56 25 | 1624 | 9.42 | 61 | -69 | -28 | 8 | 5 | 5 | |
| 314 | 10.3 | 41 23 | -52 56 15 | | 11.11 | 60 | -45 | -24 | 6 | 14 | 45 | |
| 315 | 4.6 | 40 59 | -52 56 02 | 1607 | 4.82 | 34 | | | | | | B,2 |
| 315A | 10.5 | 40 56 | -52 58 18 | | | | 110 | -74 | 13 | 10 | 0 | |
| 316 | 8.5 | 40 42 | -52 58 46 | 1600 | 8.60 | 30 | 169 | -200 | 9 | 11 | 0 | B |
| 317 | 9.7 | 38 14 | -52 59 27 | 1577 | 9.95 | 54 | -156 | 153 | 10 | 10 | 0 | 3 |
| 322 | 8.0 | 47 34 | -52 55 00 | 1684 | | | 47 | -170 | 9 | 8 | 0 | |
| 323 | 9.7 | 47 21 | -52 52 40 | 1682 | | | 126 | -181 | 5 | 7 | 0 | |
| 324 | 10.4 | 46 35 | -52 53 37 | | | | -126 | 139 | 7 | 7 | 0 | 3 |
| 325 | 10.3 | 45 58 | -52 55 36 | | | | -199 | 222 | 8 | 7 | 0 | 3 |
| 326 | 9.9 | 45 54 | -52 52 18 | 1668 | | | -10 | 29 | 8 | 4 | 78 | |
| 327 | 10.3 | 45 42 | -52 54 39 | | | | 51 | -48 | 8 | 9 | 5 | |
| 328 | 10.3 | 45 41 | -52 55 16 | | | | 13 | - 2 | 9 | 3 | 90 | |
| 329 | 10.3 | 44 32 | -52 54 11 | | | | 14 | -14 | 8 | 6 | 87 | |
| 330 | 7.4 | 43 22 | -52 53 45 | 1634 | 7.60 | 41 | -24 | 10 | 10 | 7 | 81 | B |
| 331 | 10.3 | 43 00 | -52 53 10 | | | | 10 | -17 | 7 | 7 | 87 | |
| 332 | 7.5 | 41 37 | -52 53 49 | 1622 | 7.70 | 39 | -40 | 28 | 11 | 10 | 37 | B |
| 333 | 10.2 | 41 24 | -52 51 10 | 1616 | 11.31 | 74 | 140 | -223 | 9 | 7 | 0 | |
| 334 | 10.1 | 41 20 | -52 53 19 | | 11.80 | 75 | 13 | -15 | 10 | 9 | 87 | |
| 335 | 9.9 | 41 07 | -52 50 55 | 1609 | 9.69 | 72 | 74 | -145 | 10 | 6 | 0 | |
| 336 | 5.4 | 40 53 | -52 55 10 | 1605 | 5.52 | 31 | | | | | | D,2 |
| 337 | 9.6 | 40 46 | -52 55 15 | 1602 | 9.59 | 51 | -165 | 154 | 9 | 6 | 0 | D,3 |
| 338 | 7.6 | 40 21 | -52 52 58 | 1598 | 7.59 | 27 | -21 | 39 | 5 | 10 | 51 | |
| 339 | 10.3 | 40 12 | -52 53 42 | | 12.26 | 63 | 10 | - 4 | 6 | 7 | 90 | |
| 340 | 10.2 | 40 00 | -52 54 35 | | 11.08 | 64 | 40 | 37 | 7 | 10 | 51 | |
| 341 | 10.3 | 39 50 | -52 53 41 | | 11.69 | 66 | -662 | 284 | 9 | 12 | 0 | 6 |
| 342 | 10.3 | 39 31 | -52 53 59 | | 12.09 | 67 | 43 | -10 | 7 | 15 | 62 | |
| 344 | 10.1 | 39 13 | -52 54 12 | | 12.29 | 68 | -27 | -28 | 7 | 11 | 70 | |
| 345 | 9.7 | 38 33 | -52 52 21 | | 8.88 | 76 | -81 | 146 | 15 | 8 | 0 | D,3 |
| 346 | 5.0 | 38 32 | -52 52 35 | 1579 | 5.21 | 16 | | | | | | B,2 |
| 347 | 9.9 | 37 57 | -52 50 54 | 1575 | 9.66 | 53 | 40 | 143 | 9 | 9 | 0 | 6 |
| 348 | 10.3 | 37 50 | -52 54 50 | | | | - 6 | -144 | 9 | 11 | 0 | |
| 349 | 9.5 | 37 34 | -52 50 48 | 1568 | 9.62 | 52 | -134 | 130 | 7 | 8 | 0 | 3 |
| 350 | 6.3 | 37 20 | -52 54 48 | 1565 | 6.47 | 8 | 43 | - 9 | 15 | 14 | 62 | D |
| 355 | 9.7 | 47 18 | -52 50 29 | 1681 | | | -146 | 174 | 8 | 8 | 0 | 3 |
| 356 | 9.9 | 47 16 | -52 46 44 | 1680 | | | - 3 | - 7 | 6 | 3 | 90 | |
| 357 | 10.1 | 47 08 | -52 48 51 | 1678 | | | 35 | -223 | 8 | 7 | 0 | 6 |
| 358 | 10.0 | 45 51 | -52 49 04 | 1667 | | | -18 | -12 | 8 | 7 | 85 | |
| 359 | 10.3 | 45 47 | -52 48 12 | | | | -120 | 98 | 5 | 5 | 0 | 3 |
| 360 | 9.8 | 45 32 | -52 48 09 | 1665 | 9.89 | 29 | 25 | -16 | 7 | 7 | 80 | 1 |
| 361 | 10.1 | 45 14 | -52 46 29 | 1660 | 11.57 | 15 | 10 | 0 | 6 | 7 | 90 | 1 |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_{\mu}$ | $\sigma_{\nu}$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 361A | 10.5 | 45 08 | -52 47 26 | | 12.70 | 16 | -18 | 50 | 13 | 13 | 31 | 1 |
| 361B | 10.5 | 45 05 | -52 47 01 | | 12.62 | 17 | - 1 | 12 | 6 | 7 | 89 | 1 |
| 361C | 10.5 | 45 04 | -52 49 44 | | | | 15 | 10 | 3 | 11 | 89 | |
| 361D | 10.5 | 45 01 | -52 49 16 | | | | -13 | -19 | 12 | 12 | 85 | |
| 362 | 10.1 | 44 57 | -52 47 42 | 1653 | 11.58 | 19 | 10 | - 7 | 9 | 5 | 90 | 1 |
| 363 | 9.9 | 44 50 | -52 47 16 | 1650 | 10.64 | 20 | 20 | -14 | 8 | 8 | 84 | 1 |
| 364 | 10.2 | 44 43 | -52 46 33 | | 11.84 | 22 | -83 | 112 | 10 | 10 | 0 | 1,3 |
| 365 | 9.6 | 44 43 | -52 50 37 | 1647 | 8.59 | 1 | -113 | 123 | 5 | 4 | 0 | 1,3 |
| 366 | 10.1 | 44 41 | -52 50 36 | 1646 | | | -142 | 116 | 8 | 11 | 0 | 3 |
| 367 | 7.4 | 44 16 | -52 47 17 | 1640 | 7.64 | 2 | 106 | -180 | 11 | 10 | 0 | B,1 |
| 368 | 10.2 | 44 06 | -52 47 19 | 1638 | 11.88 | 25 | -22 | 12 | 9 | 8 | 82 | 1 |
| 369 | 10.3 | 44 04 | -52 50 46 | | | | 17 | -35 | 11 | 9 | 66 | |
| 370 | 10.3 | 44 02 | -52 50 11 | | | | - 2 | 9 | 15 | 6 | 90 | |
| 371 | 10.3 | 42 33 | -52 50 10 | | | | -267 | 161 | 10 | 1 | 0 | 6 |
| 372 | 10.3 | 41 34 | -52 50 25 | | | | -18 | 43 | 14 | 10 | 47 | |
| 373 | 9.9 | 41 20 | -52 50 11 | 1614 | 10.39 | 73 | -174 | 155 | 8 | 7 | 0 | 3 |
| 374 | 7.2 | 40 44 | -52 47 15 | 1601 | 7.39 | 29 | 28 | - 8 | 11 | 7 | 82 | |
| 375 | 10.3 | 40 13 | -52 48 18 | | | | 8 | 33 | 4 | 11 | 78 | |
| 376 | 9.5 | 40 04 | -52 48 52 | 1597 | 9.21 | 26 | -367 | 96 | 9 | 7 | 0 | 6 |
| 377 | 10.1 | 39 58 | -52 48 18 | 1594 | 10.89 | 71 | 62 | -29 | 9 | 8 | 8 | |
| 378 | 10.3 | 39 20 | -52 50 16 | | | | -31 | -12 | 7 | 12 | 76 | |
| 379 | 10.1 | 39 04 | -52 50 10 | 1585 | | | -53 | - 2 | 11 | 9 | 34 | |
| 380 | 5.4 | 38 52 | -52 50 13 | 1584 | 5.60 | 21 | | | | | | B,2 |
| 380A | 10.4 | 38 27 | -52 47 16 | | | | -215 | 189 | 9 | 4 | 0 | |
| 381 | 9.1 | 38 17 | -52 47 11 | 1578 | 9.10 | 14 | -113 | 108 | 10 | 9 | 0 | 3 |
| 382 | 9.5 | 37 30 | -52 47 14 | 1567 | 10.33 | 56 | -144 | 136 | 9 | 8 | 0 | 3 |
| 382A | 9.7 | 36 57 | -52 46 13 | 1561 | | | -164 | 163 | 9 | 8 | 0 | 3 |
| 385 | 9.1 | 47 44 | -52 43 45 | 1685 | | | 11 | - 9 | 9 | 10 | 89 | |
| 386 | 10.3 | 46 33 | -52 42 30 | | | | -37 | 26 | 10 | 7 | 46 | |
| 387 | 10.0 | 46 01 | -52 42 34 | 1671 | | | 0 | 36 | 6 | 6 | 74 | |
| 387A | 10.5 | 45 05 | -52 43 48 | | | | -13 | 2 | 10 | 9 | 88 | |
| 388 | 9.3 | 45 04 | -52 41 38 | 1657 | 8.20 | 4 | 35 | - 1 | 6 | 8 | 78 | 1 |
| 389 | 10.1 | 45 03 | -52 45 30 | 1659 | 11.68 | 13 | - 4 | 5 | 6 | 6 | 90 | 1 |
| 390 | 10.1 | 45 02 | -52 45 12 | 1656 | 11.20 | 11 | 7 | - 3 | 8 | 7 | 90 | 1 |
| 391 | 10.3 | 45 02 | -52 44 42 | | 12.07 | 10 | -222 | 246 | 9 | 15 | 0 | 1 |
| 392 | 9.2 | 45 01 | -52 44 23 | 1655 | 9.41 | 9 | 43 | -44 | 9 | 9 | 14 | 1 |
| 393 | 10.3 | 45 00 | -52 45 14 | | 11.92 | 12 | 3 | 12 | 13 | 8 | 90 | 1 |
| 394 | 10.3 | 44 57 | -52 46 00 | | 12.26 | 18 | 4 | - 3 | 12 | 6 | 91 | 1 |
| 395 | 9.9 | 44 49 | -52 43 11 | 1649 | 11.15 | 7 | 25 | -15 | 7 | 5 | 81 | 1 |
| 395A | 10.3 | 44 45 | -52 46 14 | | 11.84 | 22 | 2 | 5 | 6 | 8 | 91 | 1 |
| 395B | 10.5 | 44 38 | -52 43 42 | | 12.73 | 6 | 14 | 13 | 5 | 4 | 89 | 1 |
| 396 | 10.0 | 44 28 | -52 42 49 | 1644 | 11.00 | 5 | - 3 | 30 | 9 | 2 | 80 | 1 |
| 397 | 9.2 | 44 06 | -52 45 05 | 1639 | 9.41 | 24 | -29 | 11 | 8 | 8 | 75 | 1 |
| 398 | 10.3 | 43 57 | -52 44 13 | | | | - 3 | -20 | 3 | 6 | 86 | |
| 398A | 10.4 | 43 34 | -52 46 04 | | | | -75 | 10 | 15 | 5 | 2 | |
| 398B | 10.3 | 43 07 | -52 44 36 | | | | -213 | 125 | 15 | 12 | 0 | 3 |
| 399 | 10.1 | 42 38 | -52 42 22 | 1632 | | | -176 | 193 | 8 | 8 | 0 | 3 |
| 399A | 10.3 | 41 48 | -52 45 14 | | | | -75 | 57 | 8 | 12 | 1 | |
| 400 | 10.2 | 41 32 | -52 45 49 | 1618 | | | -10 | 23 | 8 | 6 | 83 | |
| 401 | 10.3 | 40 49 | -52 45 25 | | | | 60 | 56 | 14 | 10 | 5 | |
| 402 | 10.1 | 40 48 | -52 45 14 | 1604 | | | -187 | 187 | 8 | 7 | 0 | 3 |
| 402A | 10.4 | 40 44 | -52 42 21 | | | | 4 | 10 | 15 | 13 | 90 | |
| 403 | 9.7 | 39 44 | -52 43 25 | 1592 | 9.88 | 24 | -166 | 163 | 9 | 6 | 0 | B,3 |
| 403A | 10.3 | 39 06 | -52 44 51 | | | | -12 | 52 | 12 | 13 | 33 | |
| 404 | 3.4 | 38 52 | -52 44 36 | 1583 | 3.64 | 20 | | | | | | 2 |
| 405 | 9.3 | 36 22 | -52 41 39 | 1557 | | | -57 | 127 | 9 | 11 | 0 | |
| 412 | 10.3 | 46 49 | -52 37 20 | | | | -48 | - 5 | 11 | 4 | 46 | |
| 413 | 6.2 | 46 32 | -52 39 53 | 1675 | 6.34 | 50 | - 4 | - 6 | 10 | 6 | 90 | |
| 414 | 10.3 | 46 14 | -52 40 02 | | | | -25 | -24 | 5 | 7 | 75 | |
| 415 | 10.1 | 46 13 | -52 40 54 | 1673 | | | 25 | -101 | 6 | 5 | 0 | |
| 416 | 10.2 | 45 26 | -52 41 06 | | | | - 9 | 51 | 10 | 11 | 38 | |
| 417 | 10.1 | 45 21 | -52 39 02 | 1663 | | | 12 | - 4 | 4 | 6 | 90 | |
| 417A | 10.4 | 45 00 | -52 40 33 | | | | - 3 | 46 | 6 | 17 | 54 | |
| 418 | 7.7 | 44 55 | -52 39 35 | 1652 | 7.70 | 3 | -25 | 28 | 10 | 10 | 65 | D,1 |
| 419 | 9.5 | 44 20 | -52 39 17 | 1642 | 10.33 | 27 | 29 | -28 | 8 | 9 | 64 | 1 |
| 420 | 10.3 | 43 36 | -52 38 13 | | | | -24 | 15 | 10 | 5 | 78 | |

TABLE 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 422 | 10.3 | 42 33 | -52 36 56 | | | | 74 | -24 | 6 | 5 | 2 | |
| 423 | 10.1 | 42 25 | -52 39 24 | 1629 | | | -29 | 20 | 4 | 8 | 69 | |
| 424 | 10.1 | 42 08 | -52 38 21 | 1627 | | | 3 | - 3 | 9 | 8 | 91 | |
| 425 | 10.3 | 42 04 | -52 37 53 | | | | 133 | -199 | 11 | 6 | 0 | |
| 426 | 10.1 | 41 40 | -52 39 00 | 1623 | | | -61 | 101 | 8 | 3 | 0 | 3 |
| 427 | 10.1 | 41 18 | -52 39 58 | 1612 | | | 113 | 8 | 11 | 10 | 0 | |
| 428 | 10.1 | 40 53 | -52 39 20 | | | | 67 | -39 | 9 | 5 | 2 | |
| 429 | 7.0 | 39 22 | -52 37 23 | 1587 | 7.29 | 23 | 32 | 4 | 11 | 10 | 81 | B |
| 430 | 9.9 | 37 48 | -52 35 17 | 1571 | | | 111 | 4 | 10 | 10 | 0 | |
| 431 | 10.3 | 37 30 | -52 36 54 | | | | 196 | -247 | 7 | 7 | 0 | |
| 434 | 10.3 | 47 05 | -52 35 08 | | | | 41 | -108 | 15 | 15 | 0 | |
| 435 | 10.3 | 46 57 | -52 33 24 | | | | -63 | -80 | 10 | 10 | 0 | |
| 436 | 10.3 | 46 48 | -52 32 31 | | | | -175 | 9 | 17 | 11 | 0 | 6 |
| 437 | 10.2 | 46 27 | -52 34 14 | | | | -160 | 65 | 11 | 9 | 0 | 3 |
| 438 | 10.1 | 45 19 | -52 32 54 | 1662 | | | -71 | 55 | 3 | 8 | 0 | |
| 439 | 10.1 | 45 00 | -52 33 27 | 1654 | | | 71 | -152 | 9 | 7 | 0 | |
| 440 | 10.1 | 44 42 | -52 34 42 | 1645 | | | | | | | | |
| 441 | 10.3 | 44 05 | -52 33 12 | | | | 94 | -41 | 5 | 5 | 0 | |
| 442 | 10.0 | 44 01 | -52 33 50 | 1636 | | | -104 | 124 | 6 | 7 | 0 | 3 |
| 443 | 10.3 | 42 59 | -52 31 36 | | | | -182 | 174 | 10 | 8 | 0 | 3 |
| 444 | 10.3 | 42 13 | -52 34 22 | | | | 2 | 5 | 13 | 8 | 91 | |
| 445 | 10.1 | 41 23 | -52 35 36 | 1615 | | | - 7 | -32 | 10 | 8 | 77 | |
| 446 | 8.4 | 40 40 | -52 34 35 | 1599 | 7.81 | 28 | -194 | 145 | 11 | 7 | 0 | D,3 |
| 447 | 10.1 | 39 12 | -52 33 43 | 1586 | | | -26 | 34 | 9 | 8 | 53 | |
| 448 | 8.5 | 38 35 | -52 31 31 | 1580 | 8.57 | 15 | -91 | 72 | 13 | 9 | 0 | 3 |
| 449 | 8.9 | 37 37 | -52 32 02 | 1569 | 8.78 | 10 | -148 | 108 | 12 | 9 | 0 | D,3 |
| 450 | 10.1 | 37 28 | -52 31 38 | | | | -82 | 105 | 14 | 10 | 0 | 3 |
| 451 | 9.5 | 36 40 | -52 33 57 | 1560 | | | 106 | 10 | 10 | 10 | 0 | |
| 455 | 10.1 | 46 38 | -52 29 50 | 1676 | | | -44 | 87 | 10 | 10 | 0 | |
| 456 | 9.7 | 45 26 | -52 30 03 | 1664 | | | -12 | 26 | 6 | 6 | 79 | |
| 457 | 10.3 | 44 43 | -52 30 21 | | | | - 8 | 52 | 8 | 13 | 36 | |
| 458 | 10.2 | 44 26 | -52 27 25 | | | | 11 | -15 | 11 | 8 | 87 | |
| 459 | 10.3 | 43 40 | -52 26 43 | | | | - 6 | 10 | 12 | 6 | 89 | |
| 460 | 10.3 | 42 29 | -52 30 11 | | | | -195 | 188 | 1 | 9 | 0 | 3 |
| 461 | 10.3 | 41 07 | -52 28 45 | | | | 50 | -35 | 11 | 9 | 16 | |
| 462 | 10.1 | 40 04 | -52 26 16 | 1596 | | | 33 | -27 | 7 | 9 | 59 | |
| 463 | 10.2 | 39 43 | -52 26 15 | | | | 8 | 19 | 9 | 10 | 88 | |
| 464 | 10.1 | 39 38 | -52 26 51 | 1590 | | | 899 | 318 | 8 | 7 | 0 | 6 |
| 465 | 10.3 | 38 56 | -52 27 18 | | | | -214 | 160 | 6 | 14 | 0 | 3 |
| 466 | 9.9 | 38 46 | -52 26 19 | 1582 | | | 13 | -15 | 8 | 8 | 87 | |
| 467 | 10.4 | 38 23 | -52 28 55 | | | | -34 | 18 | 11 | 6 | 63 | |
| 468 | 9.1 | 37 31 | -52 25 15 | 1566 | 9.96 | 9 | 230 | -138 | 10 | 12 | 0 | 6 |
| 469 | 10.0 | 37 21 | -52 26 05 | 1564 | | | 56 | -37 | 13 | 10 | 8 | |
| 470 | 9.7 | 37 11 | -52 27 04 | 1563 | | | -24 | 6 | 9 | 9 | 82 | |
| 471 | 10.1 | 37 02 | -52 25 09 | 1562 | | | 81 | -36 | 15 | 9 | 0 | |
| 473 | 10.1 | 45 55 | -52 26 06 | 1669 | | | 0 | -50 | 6 | 6 | 43 | |
| 474 | 9.5 | 45 04 | -52 22 45 | 1658 | | | 21 | 5 | 6 | 6 | 88 | |
| 475 | 10.3 | 44 51 | -52 22 55 | | | | -48 | 19 | 12 | 16 | 32 | |
| 476 | 9.9 | 44 19 | -52 24 38 | 1641 | | | -19 | -15 | 3 | 7 | 84 | |
| 477 | 10.2 | 43 26 | -52 24 31 | | | | -102 | 69 | 10 | 10 | 0 | 3 |
| 478 | 10.3 | 42 30 | -52 24 53 | | | | 1 | - 5 | 5 | 8 | 90 | |
| 479 | 10.1 | 42 27 | -52 23 39 | 1630 | | | -43 | -35 | 9 | 7 | 37 | |
| 480 | 10.0 | 42 17 | -52 23 41 | 1628 | | | -503 | 145 | 7 | 10 | 0 | 6 |
| 481 | 9.3 | 41 50 | -52 25 19 | 1625 | | | -172 | 141 | 10 | 10 | 0 | 3 |
| 482 | 10.2 | 41 24 | -52 21 06 | | | | 14 | -40 | 11 | 8 | 59 | |
| 483 | 10.2 | 41 19 | -52 22 07 | | | | 20 | - 7 | 9 | 7 | 87 | |
| 484 | 10.2 | 41 18 | -52 22 59 | 1613 | | | 48 | -62 | 11 | 9 | 1 | |
| 485 | 9.5 | 39 56 | -52 25 12 | 1593 | | | 33 | -56 | 9 | 10 | 9 | |
| 486 | 10.0 | 39 44 | -52 21 01 | 1591 | | | 10 | 13 | 10 | 10 | 89 | |
| 487 | 9.5 | 39 31 | -52 20 57 | 1588 | 10.63 | 57 | 92 | -28 | 15 | 11 | 0 | |
| 488 | 9.7 | 37 54 | -52 24 08 | 1572 | | | 1 | -23 | 7 | 10 | 85 | |
| 489 | 10.1 | 37 47 | -52 23 59 | | | | 16 | 8 | 11 | 12 | 89 | |
| 495 | 9.3 | 46 04 | -52 18 27 | 1672 | | | -15 | 25 | 9 | 8 | 78 | |

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| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 496 | 10.0 | 44 53 | -52 20 22 | 1651 | | | -12 | - 3 | 7 | 8 | 89 | |
| 497 | 10.1 | 44 05 | -52 19 15 | 1637 | | | -20 | -13 | 8 | 7 | 84 | |
| 498 | 10.3 | 42 44 | -52 16 15 | | | | -29 | 49 | 11 | 15 | 20 | |
| 499 | 9.5 | 41 27 | -52 19 59 | 1617 | | | -62 | 154 | 10 | 11 | 0 | 3 |
| 500 | 10.8 | 41 10 | -52 17 51 | 1610 | | | 220 | - 5 | 7 | 8 | 0 | 6 |
| 501 | 9.8 | 41 07 | -52 20 45 | 1608 | 9.64 | 36 | 8 | -41 | 8 | 9 | 61 | |

Sydney Observatory,
Observatory Park,
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# Effect of Formaldehyde on the Abiogenesis of Nucleic Acid Bases in the Irradiated Mixtures of Jeewanu, the Protocells

K. BAHADUR AND S. KUMAR*

ABSTRACT. The effect of formaldehyde has been studied on the abiogenesis of nucleic acid bases in a sterilised aqueous mixture consisting of ammonium molybdate, diammonium hydrogen phosphate and biological minerals. It was observed that the formation of nucleic acid bases increases with increasing concentration of formaldehyde up to 60 ml formaldehyde/200 ml mixture and thereafter decreases. Jeewanu, the protocells were formed by exposing sterilised aqueous mixture containing ammonium molybdate, diammonium hydrogen phosphate, biological minerals and formaldehyde to sunlight (Bahadur and Ranganayakee, 1970). The presence of nucleic acid bases (Ranganayaki, Raina and Bahadur, 1972), amino acids ( Bahadur, Verma and Singh, 1974), sugars (Raina, 1973) and lipids (Singh 1974) have been detected in the particles as well as in the environmental medium of these mixtures. Formaldehyde has been used as a source of carbon in the above mixture. The main reason for choosing formaldehyde as a source of carbon is that formaldehyde can be very easily synthesised by exposing an aqueous solution of carbon dioxide to ultraviolet light (Garrison, Morrison, Hamilton, Bensen and Calvin, 1957). Moreover formaldehyde has been detected in large quantity in interstellar space ( (Synder et. al. 1969).

EXPERIMENTAL

A set of six mixtures was prepared each having the following constituents:

| | |
|---|---|
| Ammonium molybdate | 8 g |
| Diammonium hydrogen phosphate | 18 g |
| Sodium chloride | 3 g |
| Calcium acetate | 0.5 g |
| Magnesium sulphate | 0.5 g |
| Potassium sulphate | 0.5 g |

All these constituents were taken in six separate conical flasks of 250 ml capacity. 30 ml of distilled water was added to each flask. Each mixture was boiled and concentrated hydrochloric acid was added dropwise to each flask till a clear solution was obtained. The flasks were cooled and the total mixture of each flask was made up to 100 ml with distilled water. These flasks were closed with a cotton plug and then sterilised in an autoclave at 15 lb pressure for half an hour. After sterilisation, the flasks were cooled and 36% formaldehyde solution was added aseptically to each flask as follows:-

| | formaldehyde + | sterilised distilled water |
|---|---|---|
| Flask A | 0 ml | 100 ml |
| Flask B | 20 ml | 80 ml |
| Flask C | 40 ml | 60 ml |
| Flask D | 60 ml | 40 ml |
| Flask E | 80 ml | 20 ml |
| Flask F | 100 ml | 0 ml |

These flasks were shaken gently and exposed to sunlight for six hours each day. The nucleic acid bases were detected both in the particles and the environmental medium after 4 days and 8 days of exposure.

The nucleic acid bases were identified after hydrolysing the particles and the environmental medium with 72% perchloric acid. For hydrolysis of the particles, 100 mg of the dried particles were taken in a hard glass ampule of 5 ml capacity. To this 0.5 ml of 72% perchloric acid was added. The tube was sealed and heated in a water bath for 2 hours. After cooling, the contents of the tube were taken out on a watch glass and evaporated to dryness to remove excess of perchloric acid. The residue was taken up in 0.5 ml of distilled water.

For hydrolysis of the environmental medium 2 ml of the environmental medium were taken and the hydrolysis was carried out in a similar manner as described above.

The nucleic acid bases were identified by one dimensional and two dimensional paper chromatography and finally by simultaneous running with standard compound. The developing solvents used were:-

(1) isopropanol: HCl: water : 65:16.6:18.4 (v/v)

(2) ethanol : methanol: HCl: water:25:50:6:19 (v/v)

(3) methanol : formic acid:water:160:30:10 (v/v)

The spraying reagent used was 0.25M mercuric nitrate in 0.5N nitric acid and freshly prepared ammonium sulphide solution (Voicher and Chargaff, 1951).

Quantitative estimation of adenine in the particles:

Adenine was estimated colorimetrically using zinc dust, sodium nitrate ammonium sulphamate and Bratton-Marshall reagent (Wood House, 1950).

* communicated by D.H. Napper

## RESULTS

The nucleic acid bases identified both in the particles as well as in the environmental medium are tabulated below:-

TABLE NO. 1

Nucleic acid bases identified in the particles of different mixtures containing varying concentration of formaldehyde.

| Volume of formaldehyde taken | Nucleic acid bases identified | |
|---|---|---|
| | After 4 days exposure | After 8 days exposure |
| A(0 ml) | no particles were formed | no particles were formed |
| B(20 ml) | adenine, uracil, guanine | adenine, adenosine, guanosine |
| C (40 ml) | adenine, adenosine, guanosine | adenine, uracil, cytosine, guanosine |
| D (60 ml) | adenine, guanine, cytosine, guanosine | adenine, adenosine, uracil, cytosine, guanine |
| E (80 ml) | adenine, uracil, cytosine | adenine, adenosine and uracil |
| F (100 ml) | adenine, cytosine | adenine, adenosine, uracil |

TABLE NO. 2

Nucleic acid bases identified in the environmental medium of different mixtures containing varying concentration of formaldehyde.

| Volume of formaldehyde taken | Nucleic acid bases identified | |
|---|---|---|
| | After 4 days exposure | After 8 days exposure |
| A (0 ml) | no nucleic acid bases could be detected | No nucleic acid bases could be detected |
| B (20 ml) | adenosine, cytosine | adenine, uracil |
| C (40 ml) | adenine, adenosine, uracil | adenine, adenosine |
| D (60 ml) | adenosine, adenine, guanosine, cytosine | adenosine, guanosine |
| E (80 ml) | adenosine, uracil | adenine, cytosine |
| F (100 ml) | adenine, uracil | adenine, adenosine |

TABLE NO. 3

Quantitative estimation of adenine formed in 100 mg of the particles in different mixtures containing varying concentration of formaldehyde.

| Volume of formaldehyde taken | adenine formed in mg/100 mg of the sample | |
|---|---|---|
| | after 4 days | after 8 days |
| A (0 ml) | no particles formed | no particles formed |
| B (20 ml) | 0.58 | 0.61 |
| C (40 ml) | 0.92 | 0.96 |
| D (60 ml) | 1.07 | 1.12 |
| E (80 ml) | 0.74 | 0.79 |
| F (100 ml) | 0.66 | 0.71 |

DISCUSSION

Formaldehyde plays a vital role in the abiogenesis of nucleic acid bases. In the mixtures without formaldehyde, no nucleic acid base could be detected. In the mixture containing 20 ml of formaldehyde, adenine, uracil and guanine were detected in the particles after 4 days exposure. As the concentration of formaldehyde was increased, the formation of nucleic acid bases also increased both in the particles as well as in the environmental medium. Maximum formation of nucleic acid bases was observed in mixture containing 60 ml of formaldehyde/200 ml of the mixture. On further increasing the concentration of formaldehyde the formation of nucleic acid bases decreased.

On increasing the period of exposure to 8 days, the formation of nucleic acid bases was increased but the increase was only about 5 to 10% more than what is observed after 4 days of exposure.

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# Magnesian Calcite at Macquarie Rivulet Delta, Lake Illawarra, New South Wales

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ABSTRACT. A thin, indurated carbonate layer comprising calcium and magnesium in varying proportions, is developed in the near subsurface of a barren, salt-encrusted zone and adjacent algal mat-covered flat at Macquarie Rivulet delta, Lake Illawarra. The presence of this layer appears anomalous since not only is the climate of the area humid with an annual rainfall in excess of 1100 mm, but furthermore, the associated sediments contain abundant decomposing organic matter and are essentially devoid of shell fragments and other detrital carbonate grains. In an attempt to understand the geochemical conditions that have given rise to precipitation of the carbonate layer, analyses have been made of the groundwaters and algal mats in addition to the associated sediments. It is concluded that although the mechanism of formation of the carbonate layer is incompletely understood, the algal mats may have exercised a controlling influence.

## INTRODUCTION

The Macquarie Rivulet delta, which protrudes out from the southwestern shore of Lake Illawarra, a coastal lagoon located approximately 80 km south of Sydney (Fig. 1), has an areal extent of about 1 $km^2$. The subaerial plain of the delta is mostly covered by grassland with scattered *Casuarina* sp. on the levees and ridges but, as the lake margin is approached, the rush *Juncus kraussi (J.maritimus)* generally becomes abundant and not infrequently the grassland gives way rather abruptly, to an algal flat with the glasswort *Salicornia quinqueflora*. Moreover, near the southeastern extent of the subaerial plain (Fig. 2), the grassland is separated from the algal flat by a barren, mud-cracked and salt-encrusted zone that varies in width up to 25 m. Although essentially devoid of shell fragments and other detrital carbonate grains, this zone and the adjacent algal flat contain in the near subsurface, a thin, persistent, indurated carbonate layer that comprises appreciable amounts of magnesium in addition to calcium. Since decomposing organic matter is prevalent in the deltaic sediments and the rainfall of the area exceeds 1100 mm annually, much of which penetrates the surface, it would be expected that in such an environment precipitation of carbonates would be inhibited by downward percolating waters charged with carbon dioxide. The primary objective of this investigation therefore, has been an elucidation of the geochemical parameters that have given rise to the development of the carbonate layer.

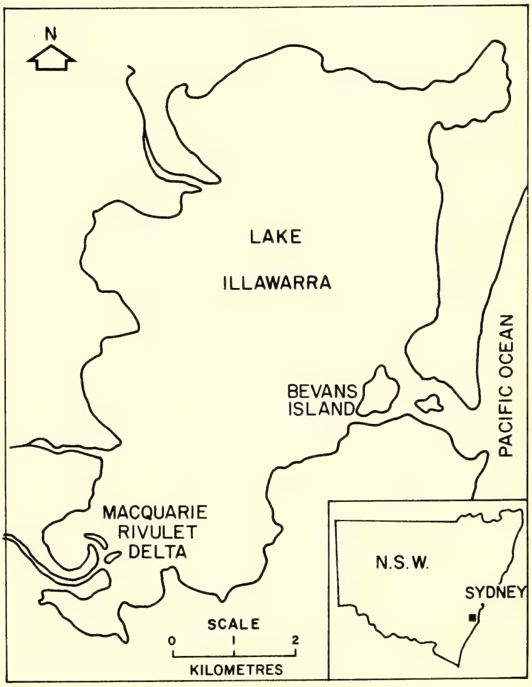


Fig. 1. Sketch map of Lake Illawarra.

## THE MACQUARIE RIVULET DELTA

The Macquarie Rivulet, which is the largest stream draining into Lake Illawarra, rises in the highlands of the southern Sydney Basin where the rainfall is 1500 mm, and flows in an easterly direction. The upper reaches drain Tertiary basalt and shales of the Triassic Wianamatta Group before descending the escarpment of the Hawkesbury Sandstone to the more easily erodable strata of the Narrabeen Group and the underlying Late Permian Illawarra Coal Measures. Because of the rapid runoff over this section, a large mass of alluvial and colluvial debris has accumulated at the base of the escarpment. In its lower course the stream traverses lavas and volcanic sandstones of the Middle Permian Gerringong Volcanics or soil and alluvium derived from these rocks. Young (1976) believed that the alluvial and colluvial accumulations on the hillsides at the base of the escarpment supplied the bulk of the detritus for construction of the delta but, judging from the prevalence of feldspar in the deltaic sediments, it would appear that the Gerringong Volcanics have also been a major contributor.

The delta, which is of the birdsfoot type, projects about 1.5 km out from the shorelines of adjacent Koona and Hayward's Bays (Fig. 2). Most of its growth has been over the past hundred years (Young, 1976) and is undoubtedly attributable to accelerated erosion resulting from the clearing of the natural vegetation to make way for urban and agricultural development. Prior to the floods of 1974 and 1975, discharge into the lake was principally through the northern distributary but the

eastern channel, which is located on the site of an earlier crevasse, was considerably widened by these floods and now forms the main outlet. As Young (1976) noted, the delta is mostly constructed of the coarse fraction of the stream-borne debris whereas much of the clay and silt has been carried well beyond the mouths of the distributaries. Some of this fine detritus is being swept into Koona Bay, particularly during periods of high lake-water level, by waves generated by easterly and northeasterly winds. As a result, the shoreline of Koona Bay, including the southern margin of the delta, is prograding rapidly (Jones et al., 1976).

Brown (1968) has drawn attention to the influence of longshore currents on the growth of the delta. As the levees were extended out into the lake, curved spits developed on the down-currents side and these eventually grew to enclose lagoons. Ultimately the lagoons were filled with fine grained detritus leaving shallow depressions separated by low ridges over much of the subaerial delta.

The small lagoon located on the southeastern flank of the delta (Fig. 2) represents an intermediate stage in the development of one of these depressions. At times of high lake levels this lagoon is filled with marine water but, during protracted arid spells, it may dry out completely leaving a thin residual crust of gypsum and halite. However, there does not appear to be a build up of these salts on the floor of the lagoon and apparently the crust is destroyed during the ensuing period of inundation.

Although Lake Illawarra is virtually non-tidal, fluctuations in water level of the order of half a metre, brought about by the intermittent opening and closing of the lake entrance and variations in stream discharge into the lake, are apparently of sufficient frequency to maintain a saltmarsh environment along part of the foreshore including the southern margin of the delta. In this environment the glasswort *Salicornia quinqueflora* tends to flourish and blue-green algae have built almost continuous mats (Fig. 4). The uppermost layer of these mats comprises *Lyngbya* sp. and *Microcoleus* sp. and appears relatively free of sediment and particulate matter whereas the underlying layer, consisting of *Trichodesmium* sp. and *Microcoleus* sp., contains appreciable amounts of solid sediment adsorbed on the algal filaments (S. Lupton - pers. comm.). The carbonate layer is generally located within a few centimetres of the base of the algal mats.

The succeeding barren, salt encrusted zone contains mud cracks and stromatolites in addition to the layer of magnesium-calcium carbonate in the sub-surface, features that have been recorded from a range of supratidal zones including those of humid areas (Shinn et al., 1965) as well as the extremely arid sabkhas (Illing et al., 1965; Kinsman, 1969). It is slightly more elevated than the algal flat and apparently encroachment by lake water does not reach this zone or is too infrequent to support algal growth. Nevertheless, the presence of stromatolites in the surface mud immediately above the carbonate layer attests to the former development of algal mats and presumably in the recent past the lake level stood somewhat higher. Wind blown spray would seem the most likely source for the accumulation of salt and apparently replenishment by this means is adequate to offset loss through solution by meteoric water and also, to inhibit the spread of grass across the zone.

## CHEMICAL AND MINERALOGICAL DATA

In an attempt to gain an understanding of the geochemical conditions that have given rise to precipitation of the carbonate layer, a series of auger holes extending from near the lake edge to the margin of the grassland, were put down (Fig. 3). Representative samples of the sediments were obtained

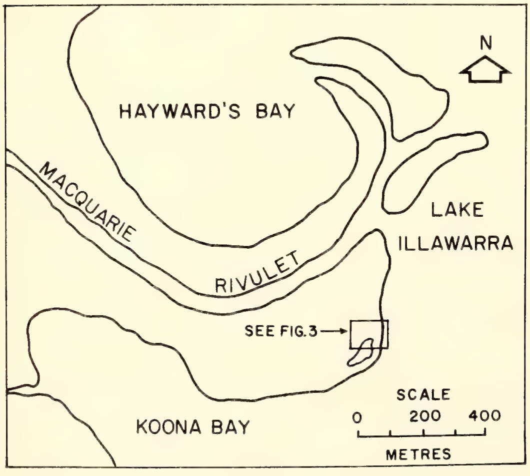


Fig. 2. Sketch map of the Macquarie Rivulet delta.

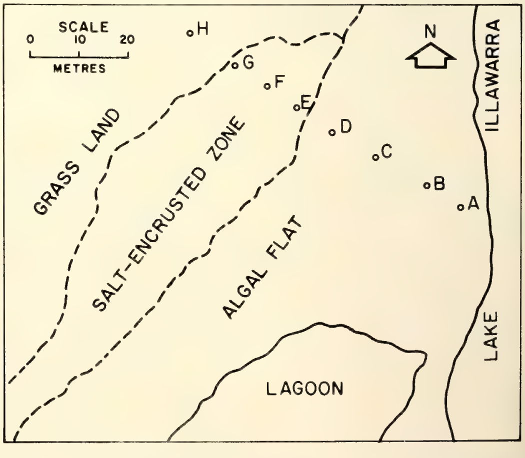


Fig. 3. Location of the auger holes in relation to the algal flat, salt-encrusted zone and grassland.

Fig. 4. Part of algal flat. Note algal polygons and glasswort.

for determination of the mineral composition and pH measurements of the groundwater in each of the holes were made *in situ* using a portable meter. Samples of the groundwater were also collected for determination of the calcium, magnesium, sodium and chlorine contents and similar analyses were made of the lake water for comparison. In addition, samples of the carbonate layer, the algal mats and the glasswort were initially washed in distilled water to remove adhering salt and sediment and subsequently, analysed for their calcium and magnesium contents.

Water analyses

As shown in Table 1, the pH value of the lake water is 8.3 but the groundwaters in the auger holes tend to be more acidic due to the concentration of bicarbonate ions arising from the decay of organic matter. The lowest reading was for hole A where organic matter is most abundant, whereas the remaining holes yielded values about or slightly above neutrality. The curve for the variation in pH values across the algal flat and salt-encrusted zone (Fig. 5) appears characteristic of coastal sections generally, including the sabkhas of the Persian Gulf (Illing et al., 1965).

The chlorinity expressed in parts per thousand, decreases from 18.5 at the lake edge to 13.2 in hole A but from there it increases gradually to a maximum of 22.3 in hole E, which is located near the outer margin of the salt-encrusted zone. Although the trend of the curve shown in Fig. 5 bears a resemblance to that furnished by Illing et al., (1965) for the Faishakh Sabkha, the values are appreciably lower and undoubtedly reflect the greater humidity of the Macquarie Rivulet delta.

In general, the Mg/Ca ratios for the samples of groundwater obtained from the auger holes do not deviate greatly from that of the lake water. Nevertheless, there is a tendency toward a higher concentration of magnesium relative to calcium in

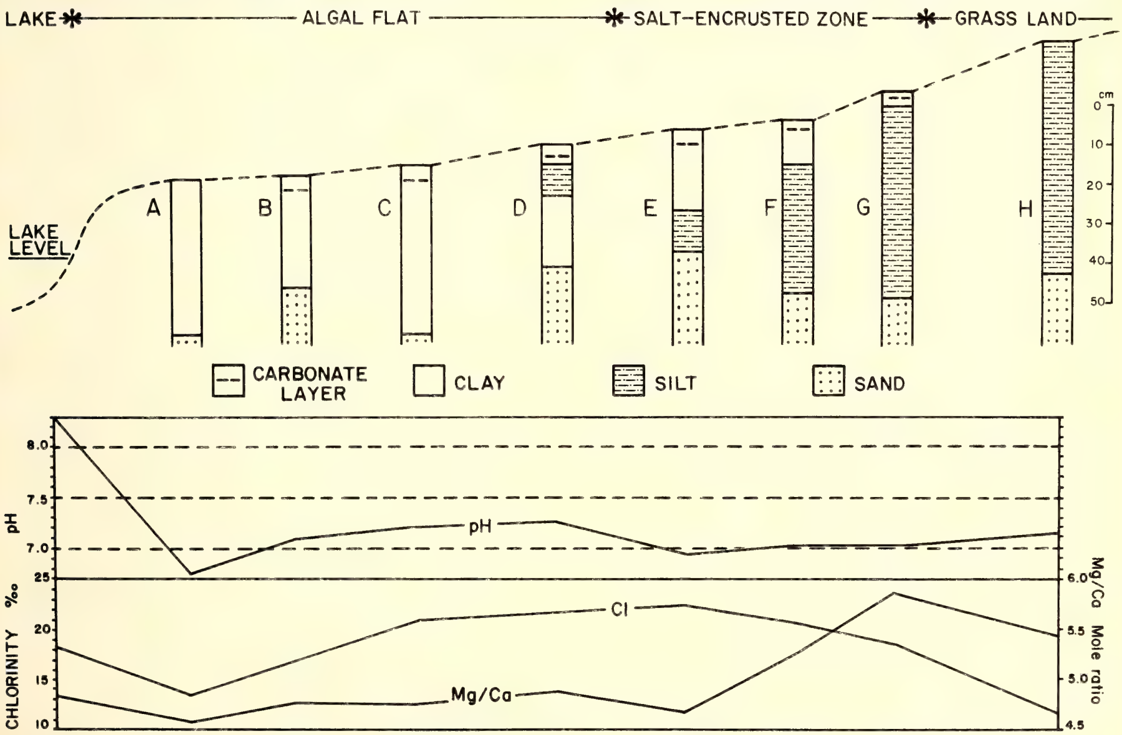


Fig. 5. Sedimentary sections encountered in the auger holes and variations in pH, chlorinity and Mg/Ca mole ratio across the algal flat and salt-encrusted zone.

the holes closest to the grassland.

Detrital mineral composition

From petrographic and X-ray diffraction analyses of the sediments obtained from various levels above the water-table in the auger holes, it is apparent that quartz is the dominant detrital mineral, not only of the silts and sands but also of the muddy surface layer. Feldspar, which in some samples amounts to nearly 20% of the total mineral content of the sediment, is almost invariably associated with the quartz occurring as discrete grains and less frequently as a constituent of rock fragments. Disordered kaolinite is by far the most abundant of the clay minerals being frequently present to the exclusion of other members of the group. Nevertheless, minor amounts of mixed layer clay minerals and highly degraded illite were detected in some samples. The predominance of kaolinite over the other clay minerals undoubtedly reflects the influence of the high rainfall on the decomposition of the source rocks. However, possibly there has been preferential concentration of the mineral as a result of differential flocculation by the marine water.

Similar analyses made of washed samples of the algal mats revealed that quartz and feldspar are the only crystalline phases present.

Authigenic minerals

Halite and magnesian calcite were the only non-detrital minerals detected in the sediments intersected in the auger holes. Gypsum was found associated with halite on the floor of the dried out lagoon during one of the visits to the area but this mineral appears absent from the subsurface samples, a point that seems pertinent to discussion of the origin of the magnesian calcite.

Halite, which varies in content up to 10% of the total constituents, was encountered in about half the number of samples of sediment examined from the auger holes. Its distribution within the sedimentary succession however, appears somewhat random.

Magnesian calcite is mainly confined to the persistent layer located from 2 cm to 8 cm below the surface of both the algal flat and salt-encrusted zone. In this layer, which has a thickness of only a few centimetres, it is fine grained to micritic and infills desiccation fractures as well as the interstices between siltsize quartz and feldspar grains. It has also been found lower in the sequence as a cement in small fragments and nodules that probably represent remnants of an earlier formed layer.

As shown in Table 2, the composition of the magnesian calcite is quite variable with some samples tending to approach the Mg/Ca mole ratio of dolomite, and this is borne out by the X-ray diffraction data. The 10.4 spacing, which is the only reflection observed on the X-ray charts, is generally very broad and lies between 2.90 Å and 2.99 Å (cf. the 10.4 spacing for dolomite at 2.886 Å and for calcite at 3.035 Å - Graf, 1961). Nevertheless, for some samples two or more maxima are evident within this range (Fig. 6) and where the

TABLE 1

PARTIAL ANALYSES OF THE LAKE WATER AND THE GROUNDWATERS IN THE AUGER HOLES

| Hole | Mg ‰ | Ca ‰ | Mg/Ca* | Cl ‰ | Na ‰ | pH |
|---|---|---|---|---|---|---|
| Lake | 1.26 | 0.43 | 4.83 | 18.5 | 9.21 | 8.30 |
| A | 0.89 | 0.32 | 4.56 | 13.2 | 6.48 | 6.73 |
| B | 1.16 | 0.40 | 4.78 | 16.9 | 8.53 | 7.10 |
| C | 1.53 | 0.53 | 4.76 | 21.0 | 10.43 | 7.20 |
| D | 1.54 | 0.55 | 4.79 | 21.7 | 10.57 | 7.25 |
| E | 1.54 | 0.55 | 4.62 | 22.3 | 11.12 | 6.95 |
| F | 1.41 | 0.44 | 5.28 | 20.5 | 10.03 | 7.00 |
| G | 1.28 | 0.36 | 5.86 | 18.7 | 9.34 | 7.00 |
| H | 0.72 | 0.22 | 5.45 | 11.3 | 5.73 | 7.15 |

* Mole ratio

mineral is richer in the $CaCO_3$ molecule, the peak appears less diffuse and is located closer to the 10.4 spacing of calcite. Heating the mineral at 250°C for 90 hours failed to produce detectable change to either the form or position of the reflectance.

The differential thermal curve (Fig. 7) for a sample of the carbonate layer has a sharp endothermic peak at 860°C, which is approximately midway between the two endothermic peaks registered by dolomite. The broad exothermic peak between 200°C and 600°C is attributed to oxidation of organic matter and that commencing a little before 900°C is probably due to reaction of the carbonate mineral with quartz and possibly also kaolinite.

ORIGIN OF THE MAGNESIAN CALCITE

From the chemical, X-ray and differential thermal data it is apparent that the carbonate mineral encountered in the sediments of the algal flat and the salt-encrusted zone is a highly disordered, solid solution of calcite and dolomite and that the composition is within the range assigned to high magnesian calcite (Friedman, 1964). It differs from dolomite not only in composition and lack of ordering but also, by the fact that it is a metastable phase and in time will invert through depletion of magnesium ions, to low magnesian calcite (Chave, 1952). Considering the high rainfall of the delta this inversion should proceed rapidly and hence, the mineral is of very recent origin and is probably still forming in the algal flat sediments.

The mechanism whereby $Ca^{++}$ and $Mg^{++}$ have been and apparently are being concentrated in the pore water to the point of precipitation however, seems far from clear and indeed, is linked to the "dolomite problem" (Krauskopf, 1967), one of the

TABLE 2

PARTIAL ANALYSES OF SAMPLES OF THE CARBONATE LAYER, THE ALGAL MATS AND THE GLASSWORT

| Sample | Mg % | Ca % | Mg/Ca* | Composition |
|---|---|---|---|---|
| Mg-calcite 1 | 4.6 | 14.4 | 0.52 | $Ca_{0.65}Mg_{0.35}CO_3$ |
| Mg-calcite 2 | 4.1 | 15.1 | 0.44 | $Ca_{0.69}Mg_{0.31}CO_3$ |
| Mg-calcite 3 | 1.3 | 9.5 | 0.22 | $Ca_{0.82}Mg_{0.18}CO_3$ |
| Algal mats(a) | 0.98 | 0.32 | 5.00 | - |
| Glasswort (a) | 0.97 | 0.51 | 3.14 | |

(a) on a dry basis

* Mole ratio.

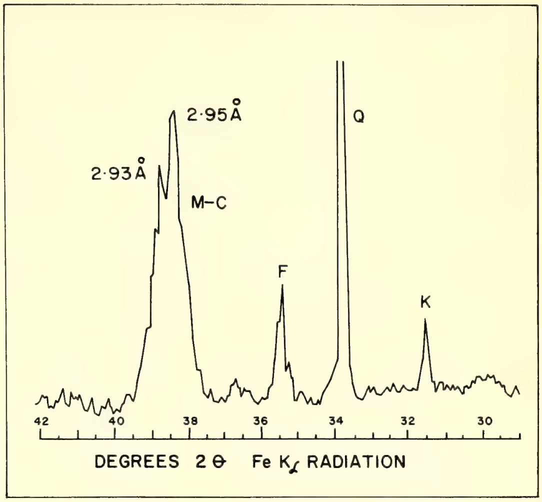


Fig. 6. Part of the X-ray diffraction trace of a sample of the magnesian calcite. M-C = magnesian calcite; F = feldspar; Q = quartz and K = kaolinite.

remaining unsolved mysteries in sedimentary geochemistry. Although dolomite and high magnesian calcite have been observed forming in a range of environments including the arid sabkhas of the Persian Gulf (Illing et al., 1965; Butler,1969), the semi arid Coorong of South Australia (Alderman & Skinner, 1957; Skinner, 1963) and the intertidal and supratidal zones of the humid Bahamas (Shinn et al., 1965), Bermuda (Friedman, 1964) and Bonaire (Deffeyes et al., 1965), they have not been synthesised at ambient temperatures when left in contact with the precipitating solutions (Glover & Sippel, 1967). Consequently, there has been much speculation on the origin of these minerals.

In the more arid areas of dolomite and high magnesian calcite development, gypsum is frequently present and this association has led to the concept that these minerals form through evaporative processes. As evaporation of the pore waters intensifies, gypsum precipitates and the brines, correspondingly enriched in magnesium relative to calcium, permeate and react with detrital aragonite and calcite fragments converting them to either high magnesian calcite or dolomite (Adams & Rhodes, 1960; Illing et al., 1965; Shinn et al., 1965). But, to invoke this mechanism for the formation of the high magnesian calcite at Macquarie Rivulet delta would introduce difficulties since neither gypsum nor carbonate detritus including shell fragments, has been encountered within the sedimentary sequence.

The aspects that seem most pertinent to discussion of the origin of the carbonate layer at Macquarie Rivulet delta are the association of the layer with algal mats or remnants of such mats, and the prevalence of $CO_2$ in the underlying sediments. Perhaps to these should be added the fact that $CO_2$ constitutes the principal, if not the sole, source of carbon for the blue-green algae (Smith, 1973). Since normal sea water is at least saturated and possibly supersaturated, with respect to $CaCO_3$ (Krauskopf, 1967), precipitation should ensue if the concentration of $Ca^{++}$ were increased or, alternatively, the partial pressure of $CO_2$ above the water table were reduced. The concentration of $Ca^{++}$ in the groundwater associated with the carbonate layer tends to be a little greater than that of sea water but precipitation is inhibited by the release of $CO_2$ from the decaying organic matter. Nevertheless, it is possible that at times of active mat growth, assimilation and hence, reduction in the partial pressure of carbon dioxide, or even the direct uptake of bicarbonate ions, by the algae is sufficient to promote local precipitation of carbonates.

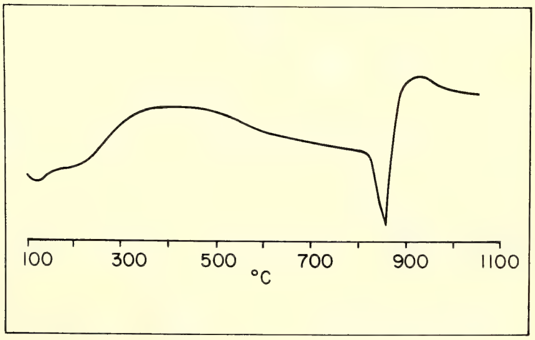


Fig. 7. Differential thermal curve for a sample of the magnesian calcite layer.

Alternatively, since the algal mats contain both $Ca^{++}$ and $Mg^{++}$ (Table 2), the high magnesian calcite may have been derived directly from the mats. Pertinent in this respect, Gebelein and Hoffman (quoted by Golubic, 1973) found that sheaths of blue-green algae are capable of accumulating $Mg^{++}$ in concentrations up to 5 times that of sea water while Monty (1967), from a study of magnesian calcites at Andros Island in the Bahamas, concluded that the mineral is mostly precipitated within blue-green algal mats. These views also accord with those expressed earlier by Chave (1952) that solid solutions of calcite and dolomite can arise only through deposition from organisms and that "inorganically precipitated calcites almost invariably show less than 2 per cent $MgCO_3$". The principal difficulty with this concept in accounting for the origin of the magnesian calcite at Macquarie Rivulet delta, however seems to be the distance separating the carbonate layer from the algal mats for if the layer were derived from the algae, a more intimate association would be expected.

Nevertheless, irrespective of the actual mechanism of formation of the high magnesian calcite at Macquarie Rivulet delta, it is apparent that neither an arid climate nor the presence of calcite and aragonite detritus was an essential prerequisite.

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# An Occurrence of the Camerate Crinoid Genus Eumorphocrinus in the Early Carboniferous of New South Wales

I. D. Lindley

ABSTRACT. *Eumorphocrinus elongatus* n. sp. from the Early Carboniferous of the upper Hunter Valley in New South Wales marks the first record of the primitive actinocrinitid (Crinoidea: Camerata) genus in the Southern Hemisphere. *Eumorphocrinus* has been previously known from the early Viséan of the British Isles and from the early Osagean of Arizona.

## INTRODUCTION

The genus *Eumorphocrinus* was established by J. Wright (1955, p. 232) and includes three definitely assigned species. *Eumorphocrinus*, considered by Brower (1969) to have the most primitive ray and interbrachial structure known in the Actinocrinitidae, is believed to be a direct descendant of the Periechocrinidae. Both the periechocrinids and *Eumorphocrinus* are characterised by the retention of many fixed-brachials in the aboral cup structure as well as having strongly grouped non-protuberant rays. As Brower (1969) states, virtually the only difference between the two groups is the number of plates in the second range of the CD interray.

Actinocrinitids with features similar to those of *Eumorphocrinus* have been assigned to Subfamily Eumorphocrininae by Ubaghs (1978). Along with *Eumorphocrinus*, the subfamily also includes *Cytidocrinus* Kirk (1944), *Maligneocrinus* Laudon, Parks and Spreng (1952) and *Manillocrinus* Campbell and Bein (1971). The genus *Manillocrinus* is the only other eumorphocrininid that has been found in the Early Carboniferous of New South Wales.

## SYSTEMATIC PALAEONTOLOGY

Subclass CAMERATA Wachsmuth & Springer, 1885
Order MONOBATHRIDA Moore & Laudon, 1943
Suborder COMPSOCRININA Ubaghs, 1978
Superfamily PERIECHOCRINACEA Bronn, 1849
Family ACTINOCRINITIDAE Austin & Austin, 1842
Subfamily EUMORPHOCRININAE Ubaghs, 1978
Genus EUMORPHOCRINUS Wright, 1955

Type species *Eumorphocrinus erectus* Wright, from Coplow Knoll, Clitheroe, Lancashire.

### Diagnosis

An actinocrinitid with rays strongly grouped but not protuberant, and 2 secundibrachs. The 1st secundibrachs are incorporated in the cup structure while the 2nd secundibrachs are axillary and with the 1st, 2nd and 3rd tertibrachs may project at slight angles from the line of the cup. A hexagonal intersecundibrachial distinctly separates the half rays; brachial openings 4 in each ray. Tegmen low to steeply conical, many plated, with central anal tube.

### Remarks

The present specimen with two plates in the range following the primanal clearly can be assigned to the Actinocrinitidae. The fact that it has non-protuberant rays with 2 secundibrachials and an intersecundibrachial suggests the specimen is *Eumorphocrinus*.

The genus *Eumorphocrinus* includes three definitely assigned species all from the Early Carboniferous of the British Isles (Wright, 1955). Brower (1969) described and illustrated an eumorphocrininid form from the early Osagean Redwall Limestone of Arizona. The Redwall specimen differs from *Eumorphocrinus* in that the 1st secundibrachial, rather than the 2nd is axillary and due to the incomplete nature of the only known specimen formal description was not attempted. The Redwall form is more advanced than *Eumorphocrinus* with the development of an axillary 1st secundibrach.

EUMORPHOCRINUS ELONGATUS n. sp.

Figs. 1 & 2.

### Description

Calyx of moderate to large size, height to distal margin of secundaxil 24 mm, width (greatest width at primaxil) 26 mm, sides rounded with aboral cup slightly constricted at top. Basal circlet clearly seen in side view with proximal portion nearly planar to slightly depressed, covered by column. Plates of aboral cup lack ornamentation.

Basals, 3, equal and pentagonal, wider than high. Proximal portion of basals slightly depressed. Radials slightly larger than basals (Table 1). Radials bordered adorally by hexagonal primibrachials which are wider than high. First axillary heptagonal, wider than high (height/width ratio 4.6/6.2). First axillaries bordered adorally by widely hexagonal secundibrachials. These plates support a small hexagonal intersecundibrachial plate.

Secundibrachials 2 in number and rigidly incorporated into cup structure; 2nd secundibrach axillary, pentagonal and wider than high. Secundaxil bordered adorally by tertibrachials. Tertibrachs at least 3 per quarter ray. Free arms, probably 20, 4 per ray, free above 3rd tertibrachials. Higher arm structure unknown.

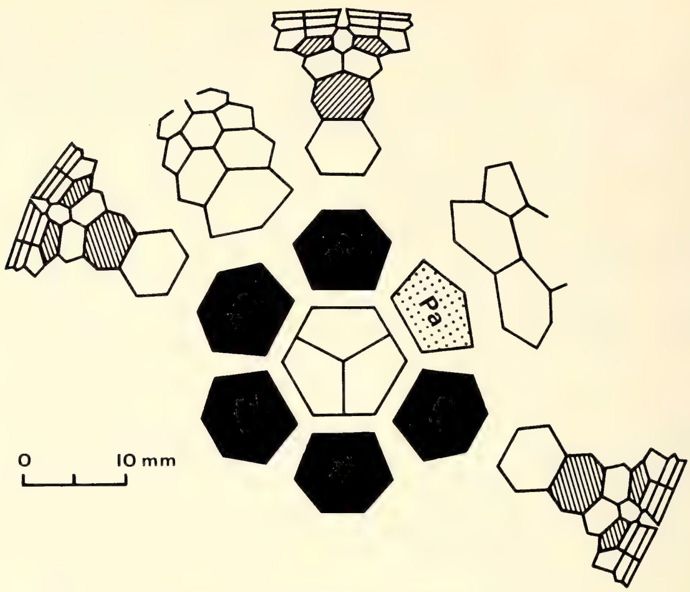


Fig. 1. Plate diagram for *Eumorphocrinus elongatus* n.sp. (radials black; axillaries hachured; primanal stippled)

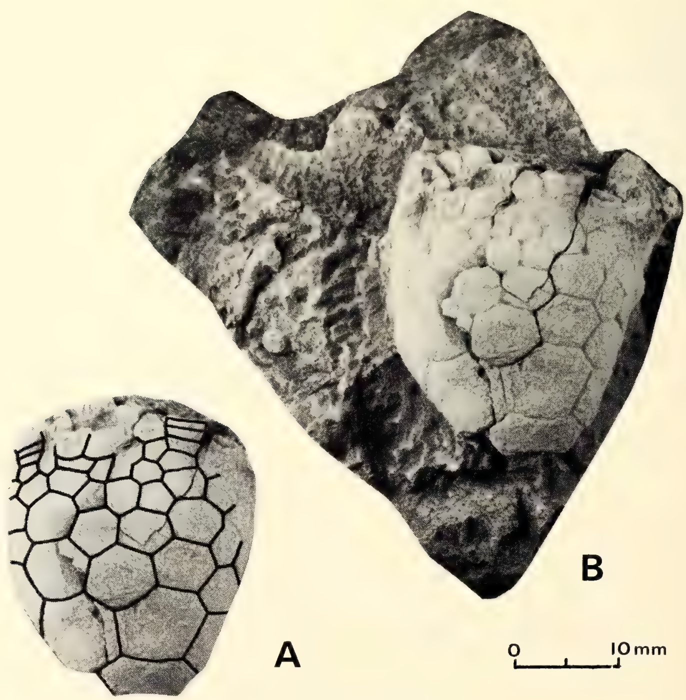


Fig. 2. *Eumorphocrinus elongatus* n. sp. A, B, Holotype, Aus. Mus. No. F.60968, lateral view, DE interray, D and E rays.

Table 1. Size and plate dimensions for Holotype of *Eumorphocrinus elongatus* n. sp.. All measurements in mm; listed values are maximum height over maximum width for each plate. "size" refers to the height of aboral cup measured from the basals to distal tip of secundaxil.

| Parameter | Aust. Mus. No. F.60968 |
|---|---|
| "size" | 24 |
| Basals | 6.2/10.0 |
| Radials | 7.6/9.0 |
| Primibrachials | 5.0/7.0 |
| Primaxils | 4.6/6.2 |
| First Secundibrachials | 2.8/4.4 |
| Secundaxils | 2.0/4.2 |
| First interbrachials | 6.6/7.0 |
| Second interbrachials | 5.0/5.0 |
| Third interbrachials | 3.4/3.2 |
| Primanal | 6.4/7.6 |
| Second anals | 5.2/6.4 |
| Third anals | 4.6/5.0 |

First interbrachials equally sided, hexagonal and bordered adorally by 2 smaller 2nd interbrachials, also hexagonal. Second interbrachials in turn followed by a row of 3 interbrachials. Adorally 3rd interbrachials are followed by a row of 3 smaller interbrachials. Adorally the interbrachials become smaller in both size and number as the ray gap size decreases.

CD interray incomplete; primanal hexagonal, slightly wider than high (height/width ratio 6.4/7.6). Primanal bordered adorally by 2 hexagonal plates. The 3rd range of the anal series probably contains 3 plates; higher plates unknown. Tegmen structure unknown.

Details of column unknown.

Material

One aboral cup: holotype Australian Museum No. F.60968. The collecting horizon is approximately 850 m above the base of the Dangarfield Formation. The upper part of the formation is considered by Roberts and Oversby (1974) to contain brachiopods of the *Pustula gracilis* Subzone of early Viséan age.

The specimen was collected from east of Glenbawn Dam, upper Hunter Valley, grid reference 030255, Woolooma 1:63,360 map sheet.

Derivation of Name

The reference (Latin: *elongatus*, elongate) is to the elongate-conical nature of the aboral cup.

Remarks

To the genus *Eumorphocrinus*, Wright (1955) assigned three species which are closely related and distinguished on the basis of cup shape, ornamentation and tegmen structure. *Eumorphocrinus elongatus* differs from the three other *Eumorphocrinus* species in various respects. It differs from *E. erectus* in that all aboral cup plates are smooth and the cup height to width ratio is larger; height/width ratio of 24/26 compared to 22/32. This also applies to the comparison between *E. elongatus* and *E. excelsus*. The third *Eumorphocrinus* species, *E. hibernicus* differs from *E. elongatus* in having a strongly rugose basal circlet, while the higher cup plates are much rounded, also having a coarse rugose ornament. Wright does not record any cup measurements for this species.

The occurrence of *Eumorphocrinus* in New South Wales is biogeographically significant in that the genus was previously known from three species all of which are restricted to the British Isles. *E. erectus* and *E. excelsus* are recorded from the Coplow Bank Beds, Coplow Quarry, Clitheroe, Lancashire, of early Viséan age (Miller & Grayson,1971), whilst *E. hibernicus* is derived from the early Viséan of Northern Ireland. As well as these species, *Eumorphocrinus*, or a form with affinities to the genus, is known from the early Osagean Redwall Limestone in Northern Arizona. The occurrence of the genus in New South Wales is most significant in that *Eumorphocrinus*, the most primitive of the Actinocrinitidae, is distributed on three continents.

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# Pre-Cleavage Folds in the Mid-Palaeozoic Sequence Near Capertee, New South Wales

CHRISTOPHER L. FERGUSSON

ABSTRACT. Meridional folds with well-developed axial plane cleavage are superimposed on earlier east-northeast trending folds in a Siluro-Devonian flyschoid and volcanoclastic sequence in the northeast Lachlan Fold Belt. The early folds have no associated cleavage and it is suggested that they may be gravity glide structures. The meridional folds are generally upright shallowly plunging structures that are part of the regional deformation of the Siluro-Devonian Hill End Trough.

## INTRODUCTION

According to Hobbs and Hopwood (1969) the Hill End Synclinorium (Fig. 1) is dominated by meridional folds with a well-developed axial surface cleavage. They suggested that to the east of the Hill End Synclinorium, concentric folding and lack of cleavage were more typical. Crook and Powell (1976) recognized folds in the Capertee Valley with similar characteristics to those developed in the Hill End Synclinorium further to the west. In these folds, rocks of appropriate ductility were observed to have an associated cleavage, similar in orientation to that in the Hill End Synclinorium. Powell *et al.* (1977) suggested that these folds and their associated cleavage developed in a single phase of deformation which they termed the "regional deformation of the Hill End Trough". In some areas it can be shown that this regional deformation postdates earlier folds, such as in the Ordovician Sofala Volcanics (Powell *et al.*, 1978).

Structural mapping (Fergusson, 1976) to the southwest of Capertee (Fig. 1) followed reconnaissance mapping by Powell (*in* Crook and Powell, 1976, Fig. 7-4), who suggested that refolding of axial surface cleavage, associated with the meridional folds, had occurred. In the more detailed structural mapping east-northeast trending folds were found with superimposed meridional folds. The presence of pre-meridional folds has resulted in: (a) macroscopic refold patterns and associated abnormal strikes; (b) mesoscopic local refolding and downward facing folds.

## STRATIGRAPHY

Crook (1955) reported Silurian greywackes from the vicinity of the Turon River-Coolamigal Creek junction. He noted their compositional variance, recognizing quartz-rich and quartz-poor types. On the basis of reconnaissance mapping Packham (1968) proposed a stratigraphic scheme for the area, with the andesitic Sofala Volcanics at the base, overlain

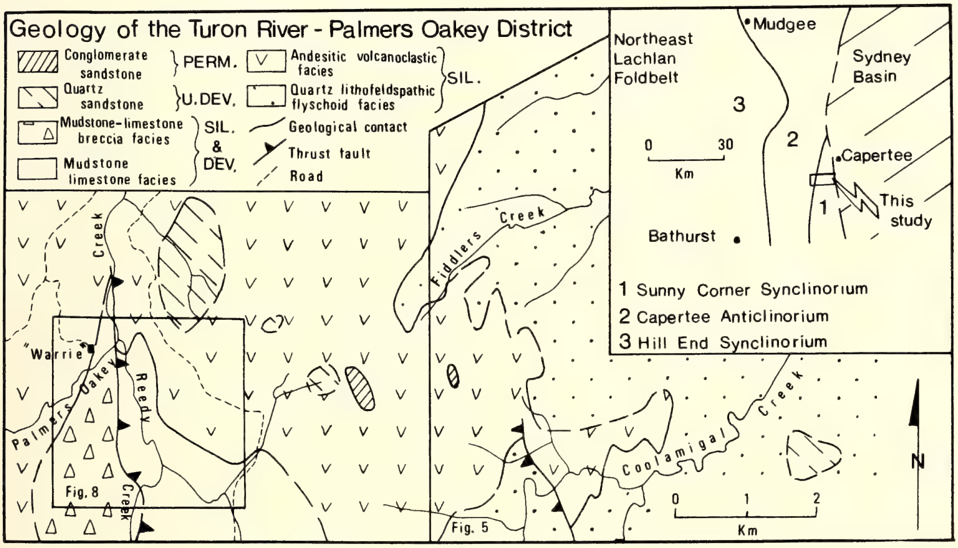


Fig. 1.

by undifferentiated Silurian and Siluro-Devonian sedimentary rocks. Packham (1969) subsequently suggested that some of these undifferentiated rocks could be equivalents of the Silurian (?) part of the Hill End Trough sequence including the Tanwarra Shale and the Chesleigh and the Cookman Formations.

In more recent work four mid-Palaeozoic facies have been recognized:

1. Quartz-lithofeldspathic flyschoid facies;
2. Andesitic volcanoclastic facies;
3. Mudstone-limestone facies;
4. Mudstone-limestone breccia facies.

Facies 2-4 are only briefly described here, as Bischoff and Fergusson (in prep.) shall describe these facies and conodont faunas of their contained limestones.

1. Quartz-lithofeldspathic flyschoid facies: this is a thick, highly deformed turbidite sequence which can be divided into two subfacies:

(a) Quartz flysch - characterised by graded beds with quartz sandstones at the base and mudstones at the top. All units of the Bouma sequence (Bouma notation units A to E; Selley, 1970) may occur, though massive graded sandstones (unit A) may be absent. Flutes and linear scours at the base of graded beds along with micro-cross-laminations (unit C), indicate a sediment movement pattern from the southwest to the northeast (Fig. 2; *see* Fergusson, 1976, for an appended list of this data and the structural data used to restore these palaeocurrents back to horizontal). Crook (1955) referred to these rocks compositionally as subgreywackes, with quartz as the major constituent;

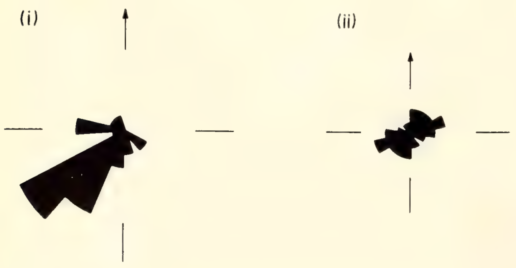


Fig. 2. Palaeocurrents for the quartz flysch subfacies: (i) 26 flutes and 6 crossbeds indicate current direction from the southwest; (ii) 14 scour lineations indicate current movement in a west-southwest and east-northeast direction.

(b) Lithofeldspathic Flysch - consists of breccias (with mafic volcanic, mudstone and chert fragments), sandstones (with feldspar and mafic volcanic grains dominant) and mudstones (Crook, 1955 has a fuller description including a triangular compositional plot). Bedding characteristics and sedimentary structures are similar to the quartz flysch except that thicker Bouma A layers are more common, expecially in lower Coolamigal Creek.

The lithofeldspathic flysch occurs as two prominent horizons, high in the flyschoid sequence. Due to poor exposure on ridges, both of these horizons are hard to trace (especially the upper horizon). On the basis of the suggested correlation (Packham, 1969) between these rocks and the Chesleigh and Cookman Formations a Late Silurian (?) age is favoured.

2. Andesitic volcanoclastic facies: consists of orthoconglomerates, massive sandstones and flinty mudstones of andesitic derivation (i.e. rocks rich in plagioclase and pyroxene). Limestones occur locally as clasts and blocks. This facies conformably overlies the quartz-lithofeldspathic flyschoid facies.

3. Mudstone-limestone facies: consists of laminated mudstones, thin bedded sheet-like limestones, minor volcanic sandstones and minor discontinuous breccias. One marker horizon, a thin quartz feldspar volcanic sandstone, crops out near Warrie. The mudstone-limestone facies conformably overlies the andesitic volcanoclastic facies. Conodonts indicate Late Silurian age (Bischoff and Fergusson, in prep.).

4. Mudstone-limestone breccia facies: consists of poorly sorted closed framework breccias in graded beds with clasts of mudstone and limestone (up to 100 metres across). This facies rests with apparent unconformity on the andesitic volcanoclastic facies and is in fault contact with the mudstone-limestone facies. Limestone clasts range in age from Late Silurian to Gedinnian indicating that deposition of the breccias must be younger than the Gedinnian (Bischoff and Fergusson, in prep.).

Crossbedded quartz sandstones (in synclinal structures) occur in the area and are regarded as possible equivalents of the Late Devonian Lambie Group. Crook (1955) also regarded an isolated patch of quartzites between Coolamigal Creek and the Turon River as Late Devonian. Outcrops of these rocks are very poor but they are thought to be separated from the older facies by an angular unconformity. Outliers of flat-lying Permian rocks also occur in the area.

## MESOSCOPIC STRUCTURES

### Group 1 ($F_1$) Folds

$F_1$ mesoscopic folds are restricted to the quartz-lithofeldspathic flysch where they are locally common. In total fifty seven $F_1$ mesoscopic folds have been found. They are variably plunging symmetrical folds that generally trend east-northeast. Their axial surfaces ($S_1$) dip at variable angles to the north-northwest ranging from steep to recumbent (Fig. 3a, b). Interlimb angles are variable, the folds ranging from tight to open. Fold hinges are typically rounded. In interbedded sandstones and mudstones, thickening of hinge zones occurs in the mudstone beds. Axial surface cleavages or fractures have not been found associated with $F_1$ minor folds.

### Group 2 ($F_2$) Folds

Over two hundred $F_2$ mesoscopic folds occur in the quartz-lithofeldspathic flysch. They have also been found in the mudstone-limestone facies (fifteen

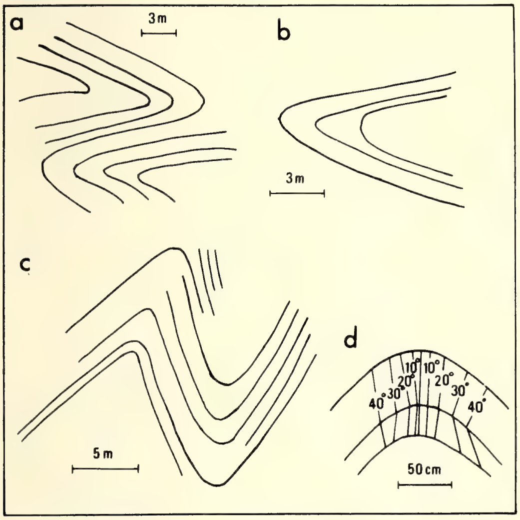


Fig. 3. Fold profiles: a-b $F_1$ folds c-d $F_2$ folds (d with dip isogons).

folds) and the andesitic volcanoclastic facies (two folds). They are typically upright, symmetrical, shallowly plunging structures that trend north-northeast (Fig. 3c, d). They vary from broad warps to tight folds but are commonly close to open. Fold hinges are well rounded. In the quartz-lithofeldspathic flysch a similar style of folding (class 2 fold profile - Ramsay, 1967) is indicated by alternation of class 1c (in the sandstone beds) and class 3 (in the mudstone beds) in interbedded sandstones and mudstones (Fig. 3d).

An axial surface cleavage is associated with $F_2$ folds. In the quartz-lithofeldspathic flysch a slaty cleavage is developed in mudstones with a 'fracture' cleavage developed in sandstones. Cleavage refraction occurs from the sandstones into the mudstones indicating that the slaty cleavage is continuous with the rough spaced jointing that is termed 'fracture' cleavage. In the andesitic volcanoclastic facies a slaty cleavage is sporadically developed in the matrix of volcanic conglomerates. Slaty cleavage is well developed in the mudstone-limestone facies. In the mudstone-limestone breccia facies a stretched pebble conglomerate occurs at G.R. 283891 (Bathurst, 1:250 000); the pebbles are flattened parallel to the plane of a strong slaty cleavage confined to the matrix with a strong elongation in the direction 61°/100° (within the cleavage plane). Otherwise no "down-dip" lineation has been found in the slaty cleavage.

Locally the meridional cleavage has been folded and kinked but this has not significantly affected the structure of the area.

Age Relationship of Group 1 ($F_1$) and Group 2 ($F_2$) Folds

From an outcrop on Coolamigal Creek (Fig. 4) it can be seen that $F_2$ folds refold, and therefore postdate, a $F_1$ fold. In the southwest corner of the outcrop upward facing $F_2$ folds are plunging to the northeast. In the northeast corner downward facing $F_2$ minor folds also plunge to the northeast (see stereogram, Fig. 4). Furthermore, a sandstone bed (stippled - Fig. 4) can be traced around from the upward facing beds in the southwest corner to a downward facing in the northeast corner. This demonstrates closure of the beds, and the points of change of facing in the outcrop define a folded $F_1$ axial trace.

There are many other outcrops where $F_2$ folds can be shown to postdate $F_1$ folds (see Fergusson, 1976 for details), for example:

1. Downward facing $F_2$ folds occur at G.R. 292897 and G.R. 292896 (Bathurst, 1:250 000).

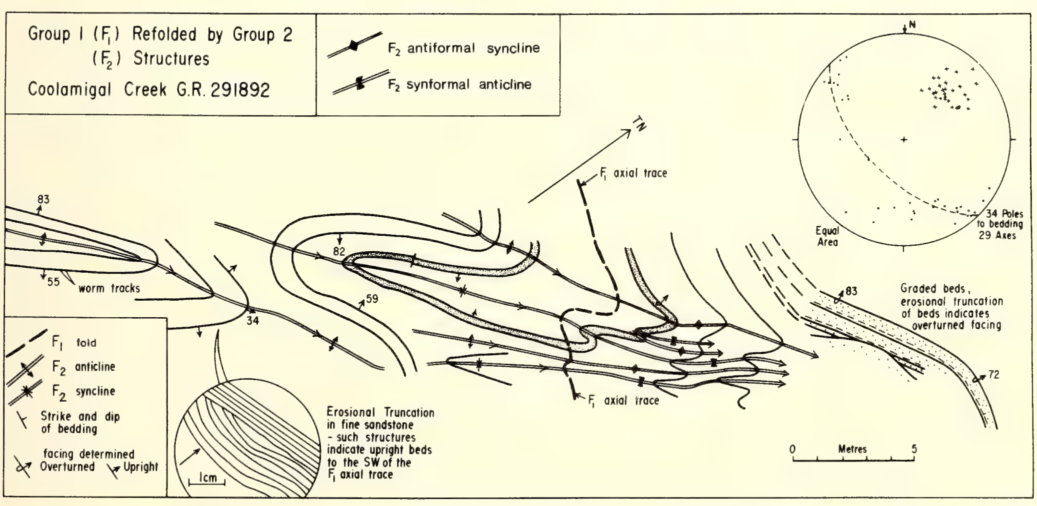


Fig. 4.


Fig. 5. Structure map of the Turon River-Coolamigal Creek area.

2. Anomalous cleavage bedding relationships - $F_2$ folds have an axial surface cleavage which is near vertical; thus on fold limbs where bedding should be upward facing, the cleavage should be steeper than bedding, assuming one phase of folding. However in the Fiddlers Creek area outcrops in which the cleavage is steeper than overturned beds are common, thereby indicating an earlier phase of folding ($F_1$).

Cleavage associated with the $F_2$ folding is itself planar and undeformed indicating that the cleavage-producing deformation was the last major deformation.

MACROSCOPIC STRUCTURES

The outcrop trace of the contact between the quartz-lithofeldspathic flysch and the andesitic volcanoclastics (defined by the highest occurrence of quartz flysch overlain by andesitic volcanoclastics) reflects the interference pattern between the early $F_1$ folds and the late $F_2$ structures. This contact trace forms an irregular hook-like pattern which extends east-west and is anomalous in comparison to other areas of north-south folding (as in the Hill End Synclinorium). Within the hook-like pattern the poorly exposed andesitic volcanoclastics provide little structural data (Fig. 5) but in the quartz-lithofeldspathic flysch common latitudinal $F_1$ folds occur and are consistent with the hook-like pattern representing a refolded $F_1$ structure. The hook-like shape is also mirrored by the lithofeldspathic marker horizons (Fig. 5).

The hook-like pattern is due to fold interference between a number of $F_2$ structures superimposed on $F_1$ structures. This resembles a "Type 2" interference pattern (Ramsay, 1967; p. 527-31). In this pattern folds with shallowly dipping axial planes are refolded by folds with upright axial planes and axial traces perpendicular to the first phase of folds. Such folds have been modelled in layered clays (Ramsay, 1967; Fig. 10-9, p. 528) and these resemble the plan pattern in Fig. 5.

Major $F_1$ Structures

The east-west trending belt of andesitic volcanoclastics (Fig. 5) indicates the presence of a major $F_1$ anticline-syncline pair. Another such pair occurs further to the north (Fig. 6) of this belt. The $F_1$ major structures have long, shallow northerly dipping limbs and steep, generally overturned limbs that face to the south (Fig. 6). The overturned limb of the $F_1$ major structure has been best preserved in the Fiddlers-Pipers Creek area (where the relict $F_1$ fold limb defines a $\pi$-axis of $10°/244°$ - Fig. 7, domain 6). This is best illustrated by the stratigraphically lower lithofeldspathic marker horizon which can be confidently followed across country from Pipers Creek to the road on the divide between Pipers Creek and Coolamigal Creek. This marker generally strikes east-northeast but has been affected in places by $F_2$ refolding (Fig. 5).

In the upper Turon River many $F_1$ folds occur in the quartz flyschoid subfacies. They are in the hinge zone of the east-northeast trending syncline containing the andesitic volcanoclastics that occurs further to the west (Fig. 5). These structures along with the common east-west strikes indicate a $\pi$-axis of $00°/249°$ (Fig. 7, domain 7). In the lithofeldspathic flysch horizon that overlies the quartz flysch in lower Coolamigal Creek, a steeply plunging $F_1$ fold pair occurs and is possibly due to rotation of these folds during the $F_2$ deformation (Fig. 7, domain 7). This horizon has also been locally offset by an east-northeast trending fault. The lithofeldspathic flysch horizon is difficult to trace in the vicinity of this fault. Structural complexity occurs as it is in the hinge zone of the interference pattern between generally east-northeast striking beds to the northwest and the apparently more meridionally folded material further south along Coolamigal Creek. Along the Turon River, in the northern part of Fig. 5, only a small number of $F_1$ folds occur (Fig. 7, domain 5) and this area is part of the $F_1$ shallowly dipping limb that has been extensively refolded. $F_2$ folds also overprint the $F_1$ structures on the andesitic volcanoclastics-quartz-lithofeldspathic contact in upper Fiddlers Creek (Fig. 5).

The presence of major $F_1$ structures in the mudstone-limestone facies and the andesitic volcanoclastic facies is indicated by steeply dipping east-west striking beds. No sign of $F_1$ folding has been found in the limited exposure of the mudstone-limestone breccia facies. In upper Palmers Oakey Creek (Fig. 8) beds of this facies appear to truncate east-southeast striking beds of the andesitic volcanoclastic facies.

Major $F_2$ Structures

Along the Turon River in the northeast of the area (Fig. 5) many major $F_2$ synclines and anticlines

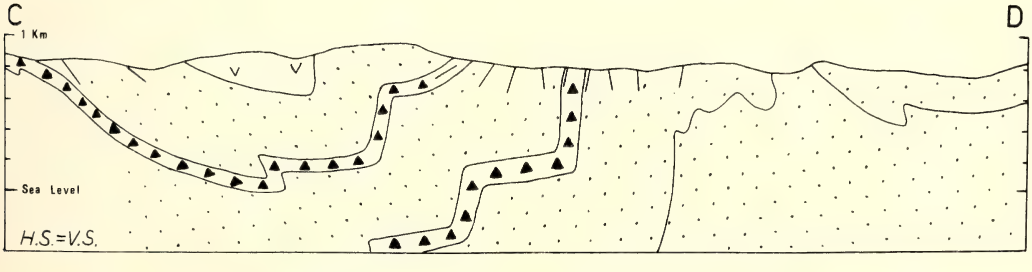


Fig. 6. Cross section CD (see Fig. 5 for location).

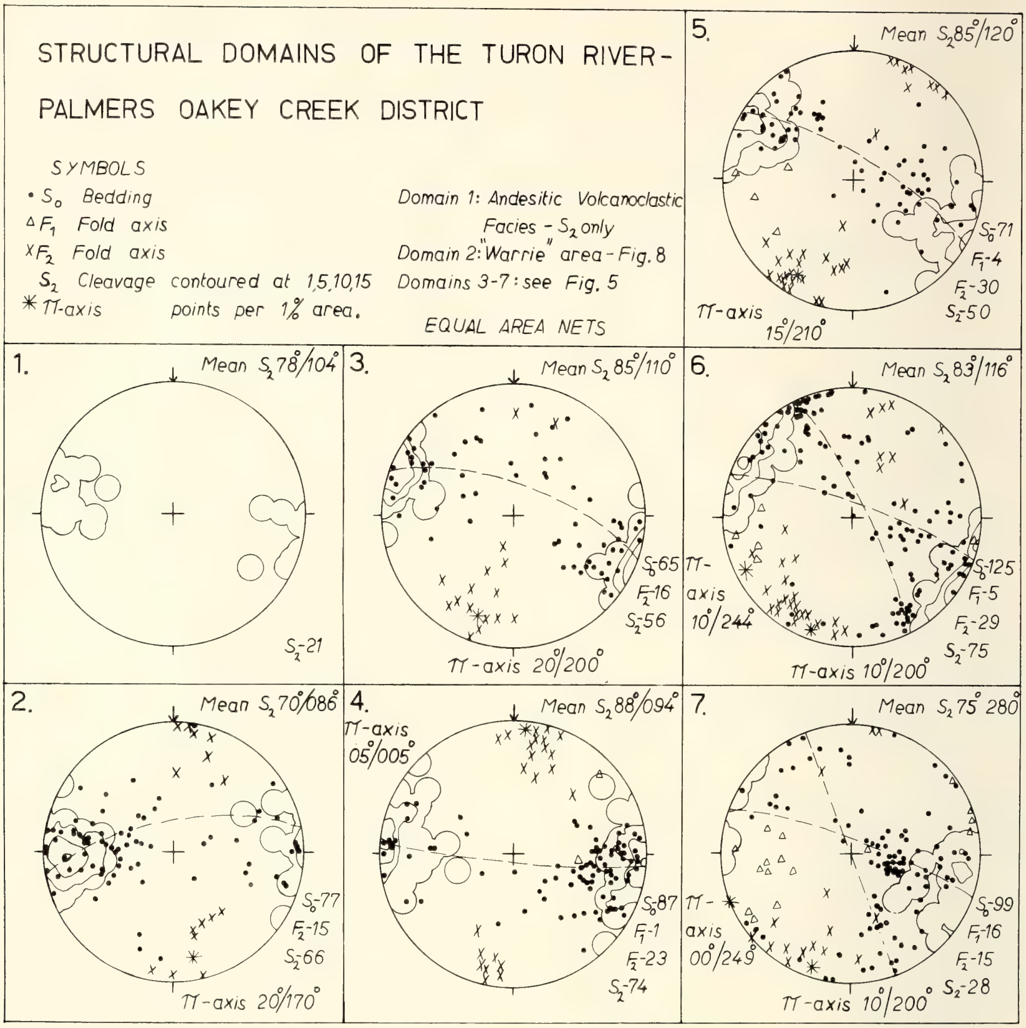


Fig. 7.

are developed. The structure is generally a westerly dipping sequence with en echelon folds developed (as for the eastern part of the Hill End Synclinorium - Crook and Powell, 1976). The structures plunge gently to 210° and are upright (average $S_2$ 85°/120°, Fig. 7, domain 5) although further east they are steeply inclined to the west.

$F_2$ structures can be traced southwards into the Fiddlers Creek area (Fig. 5) where major $F_1$ folds occur. Some of the $F_2$ folds maintain a south-southwesterly trend (Fig. 7, domains 3, 6), but some swing in orientation to a southwest trend with an accompanying change in axial plane cleavage (Fig. 5). Along Coolamigal Creek $F_2$ folds trend to the north (Fig. 7, domain 4) with upright axial planes, which are inclined steeply to the west in the east, as for the area to the north. The structure is a westerly dipping limb (Fig. 5, cross section AB) that locally is truncated by a northwest trending thrust fault between the structurally massive andesitic volcanoclastic facies and the less competent, well bedded quartz-lithofeldspathic flysch. Much of the contact area between these two facies is characterised by irregular fractures and shear planes, probably a result of the competency contract between the two units. The apparently thick lithofeldspathic flysch horizon in Coolamigal Creek appears to have been extensively folded (Fig. 5, cross section).

In the andesitic volcanoclastics dips and strikes are irregular and no stratigraphic markers have been recognized, preventing the mapping out of the major $F_1$ and $F_2$ structures (apart from along the contact with the quartz-lithofeldspathic flysch). Cleavage in these rocks (Fig. 7, domain 1) dips steeply to the east indicating that the concealed folds also have axial planes dipping in this direction. A number of very poorly exposed Late Devonian (?) rocks appear to be preserved within $F_2$ synclines (Fig. 1, see Fergusson, 1976 for more details).

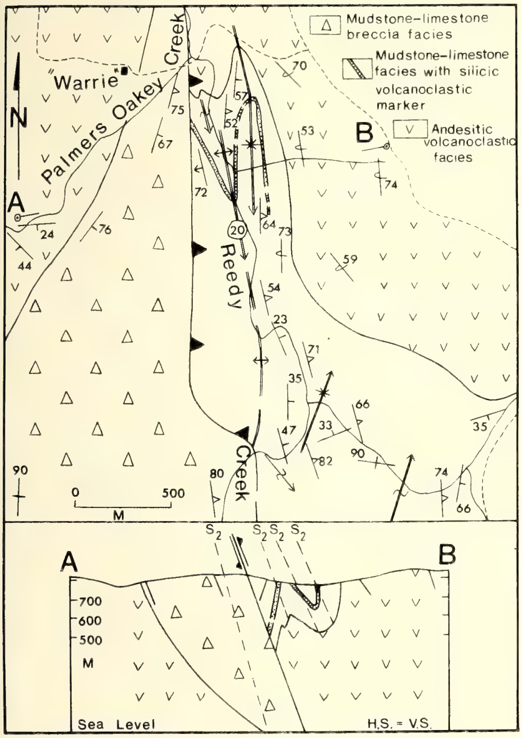


Fig. 8. Geology of the "Warrie" area. Structural symbols as for Fig. 5.

Near Warrie homestead the silicic volcanoclastic marker (Fig. 8) of the mudstone-limestone facies together with the contact between this facies and the andesitic volcanoclastics reflects a major $F_2$ syncline-anticline pair that plunges shallowly to the south-southeast. Axial surfaces dip to the east and beds are locally overturned (Fig. 7, domain 2). The meridional thrust fault separates the easterly dipping mudstone-limestone breccias from the mudstone-limestone facies.

The cleavage fans across the area, dipping to the west in the east and to the east in the west (Figs. 5 and 8). Such a cleavage fan contrasts with the area between Turondale and the Mt. Dulabree Syncline where the cleavage and axial planes of folds dips consistently to the west (Powell, *et al.*, 1977).

Scheibner's (1974) definition of the Sunny Corner Synclinorium (Fig. 1) included the area to the east of the fault in Fig. 8. This synclinorium, if upright, has a well developed cleavage fan (as occurs in the Hill End Synclinorium - Crook and Powell, 1976). However, the axis of the synclinorium does not coincide with the centre of the cleavage fan; rather it occurs well to the west, in the vicinity of the thrust fault separating the mudstone-limestone breccia from the mudstone-limestone facies, which are the youngest facies exposed in the area. The erratic distribution of Late Devonian (?) outcrops may be explained by the irregular nature of the Lambian unconformity imposed on a previously folded area.

DISCUSSION

The $F_1$ folding has been found in the quartz-lithofeldspathic flysch facies and the andesitic volcanoclastics. The conformity between the mudstone-limestone facies and the andesitic volcanoclastics (Fig. 8), as well as some steep dips with east-west strikes suggest that the former facies has been affected by this phase of folding. The structure of the neighbouring Mt Horrible and Mt Dulabree Synclines immediately to the west of the area is well known (Powell, *et al.*, 1977); Powell and Edgecombe, 1978) and no $F_1$ folds have been reported, nor has any sign of these folds been found in the Late Devonian (?) outcrops in the study area. $F_1$ folds have not been found in the mudstone-limestone breccias and a possible unconformity has been suggested although outcrop is poor in the critical areas (Fig. 8). This constrains the timing of the $F_1$ folding between the Late Silurian (age of mudstone-limestone facies) and the deposition of the quartz-rich clastics of the Late Devonian. The mudstone-limestone breccias are post-Gedinnian and the folding may be earlier.

The shallow to moderate inclinations of the axial surfaces of the $F_1$ folds and the absence of cleavage suggest a possible soft-sediment slumping origin. Stauffer and Rickard (1967) suggested a similar origin for recumbent non-cleaved folds in the Queanbeyan District of N.S.W. The dip of the axial surfaces of the $F_1$ folds would indicate a palaeoslope dipping to the south during the time of formation of these folds. Palaeocurrents from the quartz flysch indicate that palaeoslope dipped to the north-east during the deposition of these beds. Such a changing palaeoslope may be due to tectonic developments such as the formation of the Capertee High (which was obviously non-existent during the deposition of the quartz-flysch but probably influenced sedimentation during the deposition of the andesitic volcanoclastic, mudstone-limestone and mudstone-limestone breccia facies). Alternatively the $F_1$ folds may not be slump folds but of tectonic origin (that failed to form an associated cleavage).

The $F_2$ folding, faulting and cleavage forming deformation is of latest Devonian to Carboniferous age (Powell and Edgecombe, 1978; Powell, *et al.*, 1978), and has been termed the "regional deformation of the Hill End Trough" (Powell, *et al.*, 1977).

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# The Response of Coal to Geological Stimulus

G. H. TAYLOR

On this occasion each second year we honour the memory of the Reverend W.B. Clarke and I am grateful to have the opportunity to share in this recognition of a most distinguished man. It is appropriate to recall some of the many contributions which he made to our knowledge of the geology of Australia.

From 1839 onwards Clarke showed enormous enthusiasm and energy; by 1853 he had, in Ann Mozley's words "geologically, cut a swathe through the entire eastern section of New South Wales* and offered explicit evidence of the varied metal and coal resources of the Colony" (Mozley, 1965, p.98)

It was not until 1874 that an official geological surveyor was appointed in New South Wales. Quoting Mozley again: "In the long intervening year, however, it was the clergyman geologist William Branwhite Clarke who, declining the appointments of geological surveyor in Queensland, Tasmania and New Zealand, continued from his own private researches and at his own expense to advance the knowledge of the Colony's stratigraphy and palaeontology. In this period Clarke, in effect, filled the place of an official geological survey, conducting a correspondence with scientists and prospectors that might well have proved daunting to a government department; assembling collections of specimens from all parts of Australia- filling the cabinets of the Cambridge Woodwardian Museum, the Geological Society of London and the Australian Museum; and acting as a source of consultation and exchange for the growing regiment of geological surveyors in the other Colonies. Clarke's major work *Remarks on the Sedimentary Formations of New South Wales* reached its fourth edition in 1878, the year the pioneering geologist died, and two years later the accumulated details of his long and voluntary service to geology in the Colony formed the basis of the first geological map of New South Wales issued by the Mines Department." (Mozley 1965, pp 99-100)

In the 1850's, 1860's and 1870's, it was gold that was most eagerly sought, but coal also received considerable attention from Clarke, as did many other minerals - from diamonds to cinnabar. He also worked and reported on such diverse subjects as climate, deep sea soundings, and the state of the Royal Society of New South Wales.

Clarke, who lived through the latter part of the Industrial Revolution, could have had no doubt as to the importance of coal. Now, a century after his death, we have again discovered how fortunate we are in having resources of coal which are large in relation to our population. As we are forced to think more seriously of our future energy needs we are becoming more conscious of the wide variety of both brown and black coals which occur in Australia. This lecture is principally concerned with some of the reasons for this great variation and especially with the response of coal to geological events.

I have used the word 'stimulus' in the title to emphasize the sensitivity of coal to changes (including comparatively small changes in geological conditions) which produce little or no perceptible response in other rocks. The variability in the properties of coal is of interest not only with regard to the material itself, but also in providing information as to the history of rocks with which coal is associated, either in seams or as a minor component. Indeed, the study of coal and related materials has been considerably advanced to meet the needs of petroleum exploration.

The stimulus - that change in conditions which elicits a response from the coal - may be applied for times of less than a second to several geological periods. It may be local, as in minor tectonic disturbances, or regional, as when major movements of crustal plates are involved. It is also worth remembering that a number of stimuli such as tectonic disturbance, changes in heat flow, ingress of fluids, may themselves be related in time and space to a single initiating event.

Geologists working with igneous and metamorphic rocks quite generally understand these to have properties which reflect their individual histories. However, there has sometimes been an apparent unwillingness to regard coal as other than a dirty, black but, fortunately saleable, substance. The probability that we shall need to produce much more coal in the next generation than in the last, the specialized requirements of new processes, and the increasing cost of energy all make it essential that the basis of variations in coal properties should be more widely understood.

There are two broad categories of influences which determine the properties of coal and thus the way in which the coal can best be used, and so its market value. First there are those influences which determine the properties of the peat at the time it is laid down. Peat (and the coal which subsequently forms from it) is always heterogenous. Its composition in terms of macerals, minerals and lithotypes is determined by the physiography prior to and during deposition, the facies of deposition, climate, geological age (since different kinds of plants and plant communities existed at different times) and by other factors. I have chosen tonight not to dwell on any of these, important as they are.

The other influences are those which affect the seam at any time after its initial deposition. The first of these - burial subsequent to deposition - involves the question of coal rank, which is a more complex matter than is sometimes suspected. The other three influences refer to events which can occur at almost any time during the existence of the seam. However, the same event may affect brown coal and bituminous coal in very

---
* which then still included Queensland!

different ways.

In this lecture I shall draw on the work of many people, most of whom I have had the good fortune to work with - some for quite a long time. I would like to thank them and others for the stimulus they have given me over the years.

BURIAL SUBSEQUENT TO DEPOSITION

Before considering the consequences of burial I would like to refer at least briefly to the work of Shibaoka and Bennett (1975) on the ways in which a seam can be altered subsequent to deposition and prior to burial. They showed that there can be two main effects - one of extensive removal of organic matter from the seam and the other of oxidation of some of the peat remaining. These effects in the Bulli seam were recognized for what they are only after careful chemical and petrographic work, since at least two other kinds of variation in seam properties were present: (1) variations in peat originally deposited and (2) variations arising from oxidation of the mature coal *in situ*.

Probably many of you are now familiar (and perhaps over-familiar) with the rank-type diagram (Bennett and Taylor, 1970) which emphasises the importance of both type - i.e. petrographic and chemical variability at the time of deposition - and rank - i.e. the degree of coalification, maturity, diagenesis or incipient metamorphism (all these terms are used). This type of representation, although a considerable simplification, has proved useful both in assessing how different coals are related to one another and how their properties vary, and also in assessing deviations from expected properties - deviations which may be a consequence of such factors as contact metamorphism or oxidation.

We are thus concerned in this part of my talk with the response of various petrographic entities, once formed, to the changes in physical, chemical and biological environment which are a consequence of burial under younger sediments.

There are four main stages of importance in the development of a coal seam: pre-deposition, deposition, maturation and post-maturation. Not all coals have experienced the latter stage - for example coals which formed during a period of subsidence which continues without prolonged interruption to this day, as in the Bass Strait section of the Gippsland Basin. There are also coals which have been deposited, buried beneath younger sediments, uplifted with erosion of some of the younger rocks and later buried more deeply than before. In the latter case there may be two (or more) periods of maturation separated by one (or more) post-maturation stages. Such variants do not invalidate the simple model given, but require only that the principles are intelligently applied.

What is it that we are trying to express by terms such as 'rank', 'degree of coalification', 'maturation stage', and so on? Primarily we are trying to express the concept that there is a continuous, non-reversible process of change from peat through brown coal, bituminous coal and anthracite which we may, in Nature, find interrupted at any stage. This is largely a valid concept, and to the extent that it is valid, temperature acting over geologically long periods of time is the prime agent of change. Time is of great importance since equilibrium is often, probably usually, not established; geological events overtake the sedimentary basin before the coal can fully respond to higher temperature conditions.

There is, in the foregoing, an assumption which is usually unstated - that the starting materials are strictly comparable in all cases. We know, however, that there can be profound differences between macerals bearing the same name but from coals of different age or laid down in different depositional facies. Another usually unstated assumption is that the maturation process has proceeded either isochemically or at least under closely comparable conditions. However, we know this not to have been the case where we are comparing a thin parting of coal in permeable sedimentary rocks with coal within a thick seam. There is also the probability that time and temperature will not have produced exactly their expected effect when unusually high pressures and shearing forces have been involved. Unless the coal rank is very high, any deviations from the latter cause are likely to be small, even where very extensive physical dislocation of the seam has occurred.

After a thickness of new sediment has been laid down over a coal seam there is a period during which its temperature increases as a response to its new position in the sedimentary column. From observations on samples from basins subsiding at present, we conclude that the establishment of equilibrium temperature is a comparatively rapid process when matched against maturation. Shibaoka *et al.* (1978) compared two profiles, one in the Gippsland and one in the Cooper Basin. Downhole temperatures were found to be about the same at comparable depths in the two basins. However in the Gippsland Basin the coal is immature because it has had comparatively little time to respond, whereas in the Cooper Basin there has been sufficient time for maturation equilibrium to have been reached. In practice we therefore find a relationship in any one area between maturity, on the one hand, and depth of burial, rate of burial and duration of maximum burial, on the other. The absolute bed temperature will, of course, depend on the geothermal gradient which in turn is related to the heat flow and conductivity at the particular place - and this may change in the course of time.

Fig. 1 shows five simple cases which we can visualize and for which examples can be found. While more complex situations do occur, most occurrences of coal can be referred to one of the patterns shown. For example (c) is represented by the offshore Gippsland Basin and (d) by the Permian coal in the Cooper Basin. The case (e) is especially common in Australia and around the world, especially for bituminous seams where the coal is now reasonably close to the surface - e.g. much of the Sydney, Bowen and Surat Basins. Patterns of diagenesis for the Cooper, Gippsland and Sydney Basins have been considered in some detail by Shibaoka and Bennett (1977).

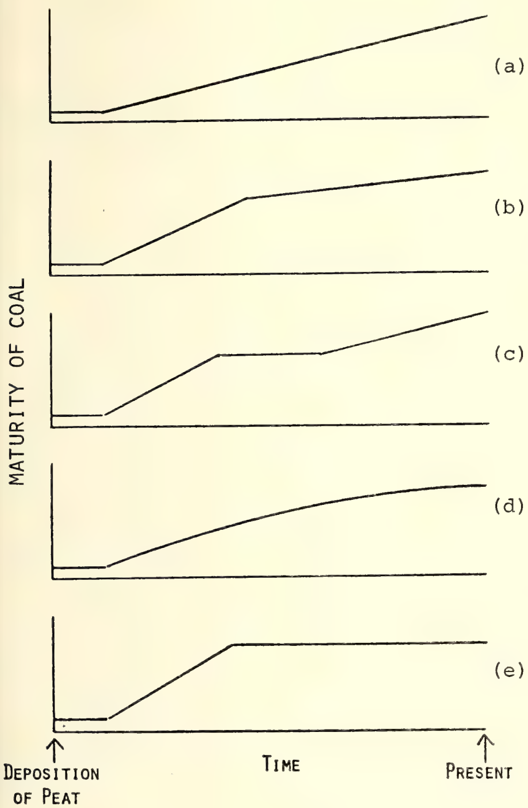


Fig. 1 Patterns of coal maturation with time

(a) continued deposition from seam formation to present with uniform heat flow

(b) continued deposition with change in heat flow (decrease shown)

(c) deposition interrupted and resumed with same (or could be different) heat flow. (Unconformity in sequence above coal measure rocks

(d) deposition ceased (or almost so) at intermediate time and no (or very little) subsequent erosion

(e) deposition ceased (or almost so) at intermediate time and erosion caused bed temperature to drop to values near those of surface.

To this point I have said nothing about the actual index of maturity or rank which may be used to characterize the profound changes which occur in coal as its temperature increases over geological time. This is not the occasion to discuss some of the problems in assessing rank and I shall say only that the microscopic measurement of the reflectance of vitrinite is a convenient and now widely used technique. It must be remembered that reflectance is not itself the rank of the coal but only one of many rank-dependent properties. I emphasize the fact that reflectance, carbon content, volatile matter yield and so on, are properties which respond to increases in rank and are not synonymous with rank. While this may sound like quibbling it is at the heart of some misunderstandings about rank, which in "absolute" terms could only be stated in terms of an equation involving temperature, time, and constants for a defined starting material maintained under defined conditions during the whole period of rank increase.

The obverse of the coal rank 'coin' is the generation of volatile materials, principally water, carbon dioxide, methane and some hydrocarbon liquids. We now look to coaly macerals, especially when dispersed through sedimentary rocks, as a major source of natural gas and, in favourable cases, of oil as well. The sequence of volatiles lost from the maturing coal is:

| | |
|---|---|
| (early) | $H_2O + CO_2$ |
| | $CO_2 + H_2O + CH_4$ |
| | $CH_4$ (and minor $CO_2 + H_2O$) |
| (late) | $CH_4$ (and minor $H_2$) |

Methane is the gas which is generated in greatest abundance during the medium volatile bituminous stage of rank when there is the greatest danger from instantaneous gas outbursts during underground mining. Paradoxically, however, the gas which is liberated in many such outbursts is not methane but a carbon dioxide-methane mixture. It had been assumed that this carbon dioxide had been retained from an earlier stage of coalification, but recent isotopic evidence (Smith and Gould, 1979) makes it clear that, in some cases at least, the $CO_2$ associated with outbursting must have been introduced into the coal and to have had a separate history.

It was mentioned earlier that coalification is an irreversible process. This is not to say that reactions between high-rank coals and, say, water do not occur. In fact such reactions may become very important where temperatures exceed 200°C. However the products are quite characteristic and bear no resemblance to low rank coals.

IGNEOUS INTRUSIONS

We have been considering the response of coal to comparatively small increases of temperature over geological time and noted that under these mild conditions the rates of response varied predictably with temperature. With igneous intrusions, we are dealing with much higher temperatures - i.e. much more energy to break chemical bonds - for shorter periods; the temperature history must always be highly variable at different locations under such conditions. Moreover the direct effects of temperature become overlaid by the effects of chemical reactions such as that of coal and water, referred to above. It is thus very difficult to generalize on the response of coal to igneous intrusions.

This is one area in which the rank of the coal is an important factor. Probably most intrusions occur, as perhaps might be expected, when coal is buried comparatively deeply and is of bituminous rank. Even within the range of the bituminous coal

stage of rank there are marked differences in response. For example coals of medium volatile bituminous rank may become highly plastic, even fluid during rapid heating, whereas coals of both lower and higher rank are less mobile. Most reactions between coal and hot igneous rocks appear to be endothermic, but this utilization of heat becomes less marked as the coal rank increases.

Because of the variables mentioned and because of differences in the petrographic composition of the coal it is not surprising that the effects of intrusions on coal differ greatly. When one also considers the diverse forms and temperatures of intrusion and the range of igneous rock types it is understandable that the volume of coal influenced may vary from trivial thicknesses of coal marginal to a dyke to wholesale alteration of a seam. Hamilton (1968) has considered many Australian instances.

Coal which is heated too rapidly for it to remain in equilibrium with the rising temperature exhibits a slightly different pattern of change in properties from coal heated slowly. For example, a brown or sub-bituminous coal at the margins of an intrusion does not become a typical bituminous coal. One difference in the two responses is that rapidly heated coal tends to 'short-circuit' the normal coalification path so that in the former case the residue is poorer, and the volatiles richer, in hydrogen. This is possibly related to the observation that pyrolytic carbon commonly occurs outside the zone of contact alteration but at no great distance from the intrusion. The unstable, volatile chemical compounds formed migrate for some distance from the intrusion but 'crack' chemically to deposit carbon in this new form in the otherwise unaffected coal.

Apart from the obviously altered zone surrounding intrusions there may be less obvious changes in larger volumes of coal. In some cases millions of tons of coal may be locally advanced in rank, but such instances are probably not common. On the basis of recent work by Williams (1979), Collinsville in Queensland may be such a case. Any such widespread effect on apparent rank is more likely when the coal is already of bituminous rank at the time of intrusion.

Of many possible examples, I will quote only two to illustrate how a knowledge of the response or non-response of coal to the stimulus of intrusion can give us information about geological conditions. I will not attempt here to give the evidence for the conclusions drawn:

1) Coal is common in the diatremes which occur in and around Sydney (Hamilton *et al.*, 1969). This coal has <u>not</u> been altered in response to a sudden thermal event, so the diatreme must have been cold at the time the coal was incorporated, and subsequently. The coal has undergone shrinkage since it became part of the breccia, and this tells us that, while the coal was immature at the time of its incorporation, it, together with the coal in the surrounding sedimentary rocks, has become mature since. The dating of spores in the coal, by Helby and others, tells us something about the time of the diatreme emplacement.

2) While my first example was of a non-response to intrusion my second example is of a rather extreme response. It concerns coal dykes such as that studied in the Hunter Valley by Britten and Taylor (1979). In this case the coal was heated at depth to a temperature of perhaps 450°C by an intrusion. Being of bituminous rank the coal became highly mobile. Whey the physical conditions permitted the formation of a higher level intrusion, the fluid coal was the most mobile material available and formed an extensive sheet-like dyke in a very short period of time - probably no more than a few seconds.

INGRESS OF FLUIDS AND THEIR PASSAGE THROUGH COAL

To this point, I have spoken more of fluids being generated from, and leaving, coal than of fluids entering coal. However there is no shortage of evidence for the entry of fluids from the earliest time of deposition to the post-maturation stage.

The infilling of uncollapsed plant cell lumens by silica, clay, carbonate and even apatite, as found by Cook (1962), is evidence of the very early activity of water. One of the most interesting cases is where a recently deposited seam or a seam with a limited cover of sedimentary rocks has been overlain by marine or brackish water. Smith and Batts (1974) have shown from the pattern of variation of sulphur isotopes how the movement of sulphate-containing water into the seam can be traced, since the sulphur fixed as a result of sulphate reduction and the sulphur laid down with the peat have quite different isotopic compositions. The effects of such movement of sulphate-rich water can be profound. Not only is sulphur added in mineral form, usually as pyrite, but sulphur is also added in organic form. Where the level of organic sulphur is comparatively high, say over 0.5%, the properties of vitrinite (such as reflectance) may be significantly affected, and can lead to problems in assessment of rank.

I have already mentioned igneous intrusions but add here that the effect of fluids accompanying intrusions may be quite marked. Much of the widespread carbonate deposition and carbonation of dyke rocks themselves which is observed must have involved juvenile, in addition to formation, waters.

The fluids entering coal may do so at a later stage than for the examples given above. At Lake Phillipson in South Australia there is a large deposit of coal which (like most South Australian coals) has unusual properties. The reflectance of the vitrinite is very low (0.28%) and comparable with the figure for Latrobe Valley brown coal. However the moisture content (12-18%) is much lower than for a Victorian brown coal. Sulphur is variable in all forms and sometimes high. Sodium and chlorine contents of the coal are high. All these figures are a consequence of the fact that the seam is an aquifer for a brine which brought in sulphate. The sulphate has been reduced in the seam to sulphide and bisulphide ions which have in part added to the organic matter. Sodium and chloride have done the same. The brine has also extracted water from the coal so that the latter is dehydrated but not advanced in rank. Because the coal shrinks as it loses moisture, it is not surprising that it may be a preferred site for an aquifer (just as a coal seam is a preferred

site for sill formation).

While the alteration at Lake Phillipson occurred at quite shallow depths, there is increasing evidence of carbon-containing materials being affected by fluids at depths of hundreds, even thousands of metres below the surface. Such evidence comes from research on the occurrence of petroleum of variable composition; it is now clear that some hydrocarbons have been oxidatively degraded by bacteria. We do not fully understand how oxygen is transferred from its ultimate source, the atmosphere, to an oil reservoir, but we can see the effects both in the degraded hydrocarbons and in the residues which include carbonate minerals of characteristic isotopic composition (Gould and Smith, 1978). Coal itself is not immune from this process and there is evidence that some seams have been mildly oxidized at depth with an effect on properties such as the degree of fluidity developed by the coal on heating. The process could be expected to be of most significance when the coal measure rocks are highly permeable, such as the sandstones in the Ipswich coal measures in southern Queensland. The effects of such mild oxidation may be detected by using the rank/type diagram described earlier, or by the use of the C-H-O triangular diagram which Stephens (1979) has been using effectively in a variety of applications.

## TECTONICS

It is still maintained by some that tectonic disturbance is an important factor in advancing rank, for example in the Dawson Tectonic Zone. There seems to be no basis for this view: the heat generated by tectonics alone is probably inadequate, in general, and unlikely to be sufficiently sustained. Nor is rank increase closely correlated with degree of tectonic disturbance. In the Bowen Basin, for example, the increase of rank is progressive and not localized where tectonic effects are most evident. We also have many situations where there is evidence of tectonic disturbance without increase of coal rank. For example:

1) In the Bowen Seam, where extensive mylonitization has occurred locally, there is no change in rank
2) The Crows Nest coal in Alberta has been very severely disturbed by the Rocky Mountains overthrust but without apparent effect on rank
3) In the Saar District of Germany, rank remains unchanged despite extensive faulting (Damberger *et al.*, 1964)
4) In the Bochum district of Germany the isorank lines more or less follow the fold pattern of the seam, so that even in intensely folded coal, the original rank has been preserved (Teichmüller, 1975)

From these and many other examples there is little doubt in my mind that tectonic disturbance has had little direct effect on the rank of coal, at least until very high rank and intense shearing are involved. In the latter case there may be some degree of graphitization; however the very great majority of coals in Australia do not show this effect.

There is one possible, indirect way in which tectonics may influence rank. Vitrinite has a structure which is anisotropic and becomes more so with increase of rank. By analogy with graphite and graphite-like structures we would expect much higher heat conductivity in the plane of the bedding of vitrinitic coal of high rank, than across it. Hence folding or rotational faulting may lead to a considerably enhanced heat flow through coal measure rocks.

Where tectonic disturbance has an undoubtedly important effect is on the strength, cohesion and permeability of coal. Certain coals, like the Greta, tend to be blocky and massive partly because in some areas they have undergone little tectonic disturbance, but partly because they have a finely heterogenous petrographic structure without many bands of pure vitrinite. Such coals tend to be comparatively little affected by mild tectonism.

Recent work by Shepherd and Fisher (1978) and others has shown how important particular joint sets are to mine roof stability. Coordinated work in CSIRO, ACIRL and BHP is also tackling the important and pressing problems of gas outbursts in New South Wales and Queensland mines. This area of enquiry brings together all four topics of this talk - the consequences of burial, the effect of igneous intrusions, the movement of fluids in coal, and tectonics.

## CONCLUSION

I would like to conclude by again emphasizing the role which many others, some named and some unnamed, have had in the work described. I have tried to avoid too much detail which would be tedious for the non-specialist, but in so doing may have seemed to make some rather dogmatic statements.

One of my objectives has been to show, through examples, the variety of geological information which is available from coal petrological studies. This information comes only when one attempts to understand the physical and chemical constitution of the materials involved in the context of the geological processes. I am glad to see more people in Australia carrying out such work since I believe it usefully complements the geological studies in this State which were begun with such distinction by W.B. Clarke and have been continued so ably by many others.

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# Life in Outer Space

R. N. Bracewell

## INTRODUCTION

Whether there is life in space elsewhere than on the earth is one of the most appealing questions for the mind to dwell on and in former centuries, as now, there was much explicit speculation. Many quotations can be given.

*Empty space is like a kingdom, and heaven and earth no more than a single individual person in that kingdom. Upon one tree are many fruits, and in one kingdom many people. How unreasonable it would be to suppose that, besides the heavens and earth which we can see, there are no other heavens and no other earths?*

Teng Mu, 13th century philosopher

*And so what mainly makes me believe that the planets have intelligent beings is that the superiority of our earth over those others would be too great if the beings had unique features so far beyond all other living beings, not to mention the plant kingdom.*

Christian Huyghens,
17th century physicist

*Observe how system into system runs;*
*What other planets circle other suns;*
*What varied being people every star.*

Alexander Pope,
18th century poet

*Homo sapiens has recently flattered and frightened himself by conceiving that, though perhaps he is not the sole intelligence in the cosmos, he is at least unique, and that worlds suited to intelligent life of any kind must be extremely rare. This view proves ludicrously false.*

W. Olaf Stapledon,
20th century writer

*"You s'pose there are Mars worms? Jupiter worms? Venus worms? Porfirio?"*

*"Panchito! It'd be gross conceit to imagine that in all those awesome endless galaxies we are the only worms!"*

Gus Arriola,
20th century cartoonist

The current surge of discussion, which began around 1960, differs in an important way from the discussion of earlier times: the philosopher of today is expected not to violate known laws of physics and to keep his scenarios compatible with the great many facts of astronomy and astrophysics that are now known. Although these restrictions make it difficult to say anything at all about life in space, nevertheless a substantial body of literature has arisen. A principal topic deals with action that humans might take to find out whether there is life elsewhere. In this category we should include the planning and execution of the Mars landings, but to reach beyond the solar system is far more difficult. A well known proposal is to listen by means of a sensitive radio receiver connected to a large radio telescope pointed in the direction of nearby stars. Project Ozma and the Cyclops design study will be recalled as exercises in this direction and some listening activity is being pursued at the present time, for example by Kraus and Dixon at Ohio State University. There is a remote chance of success so I am in favour of this enterprise but very little total effort will be exerted because most people with suitable equipment will judge that their time will be more productively spent on other endeavours. The situation would change if a very large antenna system, much larger than anything now available, could be constructed--the Cyclops study group contemplated 10,000 large radio telescopes massed together.

As it has come to be realized that direct listening is not likely to yield quick success and is likely to be very expensive, action-oriented thinking has turned to other directions. A new thought is to look for nonsolar planets rather than for life directly. If planets were discovered it would mean a big step forward for direct listening both as regards the enthusiasm for listening that would be generated and as regards the actual chance of successful detection of life. Not only intelligent life is in point. Although reception of radio communication signals from a planet would convincingly evidence the presence of technological life it is conceivable that lower forms of life could reveal their presence over interstellar distances in some other way. We must remember that the conspicuous blue of our planet as seen from the moon is due to our oxygen, which is a by-product of organic life. To a sophisticated outside observer, if there is one who can see our planets, the blue of Earth, contrasted with the white of Venus and the red of Mars would speak volumes.

We have become so accustomed through fiction to the plurality of planets belonging to other stars and even to stars of other galaxies that it is a shock to some to learn that even today there is no generally accepted evidence for the existence of any planets in the Universe other than the nine in our own solar system. There is certainly evidence for dark companions but they are objects much more massive than Earth or even than Jupiter. If a coordinated search were to be made for nonsolar planets it would be a step forward in the search for life in outer space but would also be certain to provide other sorts of astrophysical

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knowledge. This is important, for the general assent of the scientific community is necessary for the general assent of the scientific community is necessary for the initiation of large projects and the broader the prospective returns the wider the assent is likely to be. Therefore I am confident that there will be a surge in activity aimed at detection of nonsolar planets in coming years. Furthermore, I have a technique to propose. First let us consider two orthodox proposals as a background for two new ideas that space-age technology permits us to contemplate.

ASTROMETRY

One of the great traditions of astronomy is the preparation of star catalogues, an activity that was pursued by the Babylonians and the Chinese, by Hipparchus (second century B.C.) and Claudius Ptolemaeus (second century A.D.). The earliest substantial work that is extant records the positions of 1028 stars as determined by Ptolemy, whose system of classifying stars into first and second magnitude and so on is the one still in use today. A by-product of this activity was the discovery that the stars are not fixed on the celestial sphere but appear to move slowly, some faster than others. Sirius, the brightest star, has always appeared in the catalogues as they grew in length and over the years became more refined, so that by 1844 Friedrich W. Bessel (1784-1846) was able to announce a very peculiar thing about Sirius. Over the course of 50 years Sirius not only moves south by 66 seconds of arc, a very noticeable distance, but does so in a sinuous path, weaving to each side by 8 seconds of arc. Bessel announced that Sirius must possess a dark companion which if visible, would be seen on a wavy path interwoven with that of Sirius as they each revolved about their common center of mass. Thus did the first white dwarf make its presence known. Years later in 1862 it was seen and ultimately, many years later, it was photographed. It has about the same mass as our Sun, is only twice the size of the Earth and has a density of 150,000 relative to water.

This fragment of history exemplifies all the technical background needed to follow the method of astrometry as a technique for discovering nonsolar planets. A planetary companion must produce the same sinuous motion of its parent star but less in excursion according to its mass. Let us imagine a star S like our Sun possessing a planet J like Jupiter but situated 33 light years away. This distance is chosen because it is a standard distance in astronomy (the distance on which the system of absolute magnitudes is based). There are about 300 stars in a sphere of 33 light years radius. We now ask, what will the lateral excursion of S be, as we observe it year by year from Earth, under the influence of its revolving planet J. The answer is 0.5 milliseconds of arc or 16,000 times less than for Sirius under the influence of its dark companion. The technical feat that would be required to detect such a small displacement in the sky is clearly lf the greatest difficulty and may seem impossible. Bear in mind that Jupiter takes 12 years to orbit the Sun so the detection of planet J if it has a similar period would require sustained attention for many years and a means of assuring that small displacements, if detected, were the result of planetary motion and not of some instrumental change over the years. In addition remember that a star image dances about by 100 milliseconds of arc or more due to irregular refraction or twinkling of the starlight as it passes through the earth's atmosphere. In view of the difficulties imposed by the atmosphere and year-to-year changes in astrometric telescopes it is surprising to learn that the precision attainable in current astrometry, when a year's observations are combined, is 3 milliseconds of arc.

RADIAL VELOCITY

As star S rotates about the mass center not only does it weave from side to side as seen from Earth, but it also approaches and recedes. Such radial, or line-of-sight motion is not apparent as a displacement of the star on the celestial sphere, but it changes the stellar spectrum, which is subjected to Doppler shift. Under the influence of planet J, star S acquires a radial velocity of 12 metres per second on top of its mean velocity of approach or recession (which is likely to be in the range of tens of kilometres per second). Radial velocity measurement is a vigorous discipline that is practised both on stars and external galaxies but because the velocities to be measured are relatively high, great precision has not been in demand. At present precisions of about one kilometre per second are standard and 250 metres per second has been attained on the Palomar 5 metre telescope. So there is a substantial gap between current practice and what would be necessary to detect the radial velocity variation due to an orbiting planet. An encouraging aspect is that current work is done on faint stars chosen because of some characteristic such as stellar type whereas the first candidates for planetary search would be the nearby stars which are much brighter. For this reason, and taking account of foreseeable instrumental developments it is thought that a precision of 10 metres per second is technically feasible, though great effort will be required.

In the radial velocity approach, as with astrometry, observations sustained over many years will be required so that the changing effect due to the planet's orbital motion can exhibit itself. Radial velocity has the interesting feature of being independent of distance whereas the astrometric displacement falls off as distance increases. The two established procedures are thus in a sense complementary, astrometry being more favorable for the closer stars and radial velocity taking over at some as yet undetermined distance.

APODIZATION

Why cannot a nonsolar planet be photographed through a large telescope with a time exposure sufficient long to develop a planetary image? The difficulty is attested to by the fact that the dark companion of Sirius, known as Sirius B, resisted photography until quite recently. This was partly because Sirius gives 10,000 times more light than Sirius B. But that is not the full story because Sirius B is, even so, equivalent to a twelfth magnitude star which can be photographed readily with an exposure time of minutes. The other important factor is the proximity of Sirius.

As is quite noticeable on photographs of star fields, brighter stars produce larger images than fainter stars. This means that as the exposure time is increased the photographic image of a star grows in diameter and tends to obliterate any faint object in the neighbourhood. Thus the image of Sirius easily reaches a radius of 8 seconds of arc in the time necessary to bring up a detectable image of Sirius B which is then lost in the glare. The explanation of this phenomenon lies partly with light scattered through small angles of just seconds of arc by atmospheric particles, partly with imperfections of the telescope and partly with diffraction of the starlight.

While Sirius is $10^4$ times stronger than Sirius B, we calculate that star S is $10^9$ times stronger than planet J. Furthermore, while Sirius B is 8 seconds away from Sirius, planet J is only half a second away from its star, as viewed from 33 light years. Thus direct photography seems unattractive. But, action is needed, so we should take an optimistic attitude and ask what would be needed to change the situation to a favourable one. There is an answer. First, the earth's atmosphere must be eliminated, a step which the space age has rendered feasible. Indeed, sizable telescopes of several kinds have already been launched successfully into earth orbit. That deals with atmospheric scattering. Secondly, much better parabolic surfaces must be made than were manufactured for today's great working telescopes, some of the best of which date back decades. That is a matter of technology and seems to present no insuperable obstacle in principle but will present a significant engineering challenge. Finally, there is the diffraction of light which is inherent in wave propagation and describes the ability of light to go round corners as studied long ago by Francis M. Grimaldi (1619-1663), who coined "diffraction", and by Isaac Newton (1642-1727). Because of this proclivity of light rays to bend, starlight falling on a parabolic mirror is not all directed to the geometrical focal point, which is where the photographic plate is placed, but a certain amount arrives in the neighbourhood. One can calculate strictly how the light intensity falls off. As we know, it is still very strong half a second of arc away in the location of the planetary image (if such there be). Apodization is a method of reducing the strength of the diffracted light by eliminating the sharp boundary of the cylindrical beam of starlight that falls on the parabolic mirror. If the light intensity can be made to fall off from center to edge continuously instead of cutting off abruptly, there is a dramatic reduction in the amount of light that is bent away from the focus and further improvement is attainable the more smoothly the light intensity tapers off. As with the indirect methods of detection already described the indications are that in principle apodization can succeed but effort and inventive ability will be required. A major difference is this. Direct photography will not require 12 years of sustained attention. If planet J is there it will be detected promptly.

## SPINNING INFRARED INTERFEROMETER

While there are three avenues open, any of which could lead to successful detectin of non-solar planets, as far as we know now, there are significant technical unknowns which might block or delay progress. There is therefore scope for new ideas going beyond the improvement of already known methods.

Let us ask first whether visible light is the best or only way to go. Planets not only reflect the light of their sun but also emit electromagnetic radiation in their own right because of the heat they contain. In the case of Jupiter, whose temperature is -145°C, heat radiation would not seem to be of great importance because the planet is so cold. Its radiation is faint and peaks up at an infrared wavelength of about 40 micrometres. Perhaps surprisingly, the stellar radiation at this wavelength is also not very strong, in fact it is only 10,000 times stronger than that of planet J. Merely by jumping to another wavelength we therefore immensely improve the problems caused by glare at visible wavelengths where the star outshines the planet by a factor $10^9$.

With this encouraging beginning we are stimulated to seek a new principle to discriminate between star and planet. The answer is interferometry. A special infrared telescope can be imagined which collects infrared radiation from the star through two apertures about one metre in diameter and 10 metres apart. The two beams can be brought together and caused to interfere destructively if crests of one wavetrain superimpose upon troughs of the other. Radiation from the planet, on the other hand, not coming from precisely the same direction, can give rise to constructive interference and a maximum of intensity. This will happen if one of the apertures is one half wavelength closer to the planet than the other aperture, a condition that will arise automatically if the spacing is 10 metres as proposed. A star is almost a point source but not quite. The angular diameter of star S at 33 light years is one millisecond of arc. The consequence is that only a diameter of the star can be nulled out and points to each side, while they will be heavily discriminated against, are in fact not entirely suppressed. When allowance is made for the imperfect suppression, it is found that the planetary emission exceeds that of the star by 20 times.

If the beam on which the collecting apertures are mounted is allowed to spin around an axis passing to the star, the planetary signal will rise and fall at a precisely known frequency and sensitive techniques of synchronous detection may be used to detect the presence of the planet against the unchanging stellar background signal. This very simple set of concepts offers a fourth approach and warrants careful study.

Already many features have been examined. For example, the infrared instrument must operate outside the earth's atmosphere which is a stronger source of heat than the planet. All heat radiation that can be screened off, particularly solar and terrestrial heat, must be blocked by shades and thermal insulation. Heat radiation from the optical parts, mostly mirrors, and the walls of the satellite containing the detector must be stringently reduced by operating at extremely low temperatures, such as the boiling point of helium. Techniques of this sort are already established for space

vehicles of other kinds but a cryostat of the necessary size is not a trifle. Elaborate laser servos are needed to keep the infrared optics in adjustment and a star tracker to keep the interferometer spin axis aimed at the star. Although these elements are already well understood also, successful operation will demand the highest traditions of instrument design.

As with direct detection by apodization, the spinning infrared interferometer does not require 12 years of observation but the time required may well be many months. The reason for this would not be easily foreseen. In the vicinity of the Earth, and more or less in the plane of its orbit, there are solid particles about one micrometre in diameter and about one kilometre apart, on the average, that give rise to the zodiacal light, scattered sunlight that can be seen stretching out along the zodiac when the sun is just below the horizon. Because of smog, very few people are familiar with the zodiacal light these days. The best time to look is on a clear autumn evening when there is no moon. In spite of the sparsity and fineness of the particles, they are at about Earth temperature and it is thought that there are enough in the field of view of the infrared instrument to limit the sensitivity. The quality of the infrared detectors themselves is not likely to be limiting unless in future years infrared interferometers are launched out of the ecliptic plane or on voyages well beyond Mars where the particles have proved to be undetectable.

Many fascinating problems are presented by this novel concept. As yet it is too early to estimate the relative costs and relative chances of success of the four approaches that have been described. If history is any guide, however, we may be sure that all of these projects, which represent substantial advances on current instruments, are likely to produce discoveries of phenomena more conspicuous than the minute planetary effects that are sought but too faint to have been noticed hitherto.

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# The Volatile Leaf Oils of Three Species of Melaleuca

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ABSTRACT. The compositions of the steam-volatile leaf oils of *Melaleuca adnata, M. nodosa* and *M. thymifolia* were determined by the use of gas-liquid chromatography and mass spectrometry. The oils of *M. adnata* and *M. nodosa* were characterised by high proportions of 1,8-cineole. *M. thymifolia* has been shown to exist in an α-pinene rich form.

## INTRODUCTION

In continuation of our research into the native Australian essential oil bearing flora we have examined the volatile leaf oils of *Melaleuca adnata* Turcz., *M. nodosa* Sm. and *M. thymifolia* Sm. The leaf oils of the two latter species have been briefly examined by earlier workers who reported 1,8-cineole (53% of oil) in *M. thymifolia* (Baker and Smith, 1906) and 1,8-cineole (33% of oil) and *d*-α-pinene in *M. nodosa* (Baker and Smith, 1907). Penfold and Morrison (1929) reinvestigated *M. nodosa* (erroneously referred to in their paper as *M. nodosa* var. *tenuifolia* DC; D. Blaxell, pers. comm.) and identified, in addition to 1,8-cineole 40-55% of oils) and α-pinene, small amounts of dipentene and α-terpineol.

## RESULTS AND DISCUSSION

In the present investigation freshly obtained oils were analysed by a combination of gas-liquid chromatography (g.l.c.) and mass spectrometry. The results, presented in Table 1, show that all three species yielded chemically unexceptional, albeit much more complex oils than reported earlier. They do present, though, some features of chemotaxonomic interest.

Both *M. nodosa* and *M. thyrifolia* appear to exhibit considerable quantitative variation in some of their oil constituents. The 1,8-cineole content of *M. nodosa* oil ranges from 33% (Baker and Smith, 1907) to about 41% and 55% in our samples and 40-55% in those of Penfold and Morrison (1929). α-Pinene varies between even wider limits: from 6% and about 30% in our samples to approximately 60% (Baker and Smith, 1907). In both cases the variation appears to be continuous and consequently separation into chemical forms is not warranted. The chemical variation in *M. thymifolia* is more pronounced. The 1,8-cineole and α-pinene contents of our sample were 1% and 84% respectively, whereas Baker and Smith (1906) reported 53% 1,8-cineole but no α-pinene at all. Even if a small amount of α-pinene had been present, but escaped detection owing to insufficiently sensitive analytical methods, the magnitude of the variation is such that the existence of chemical forms is probable. Intra-specific chemical variation of this type is common not only in the genus *Melaleuca*, but in the family Myrtaceae in general (Hegnauer, 1969).

Finally, the suggested presence of *iso*borneol in the oils of all three species should be commented upon. *Iso*borneol has not, to the writer's knowledge, been reported from *Melaleuca* before. Since Baker and Smith (1906) noted a trace of an alcohol with a borneol-like odour in the oil of *M. thymifolia* and since borneol occurs, though rarely, in myrtaceous oils (Jone and Lahey, 1938) a careful search was made for it. None of the peaks present in our gas chromatograms corresponded to borneol. However, a small peak common to all oils coinjected with *iso*borneol. Its mass spectrum supported this identification. Unfortunately, the very small amounts of oil available did not allow a physical separation of the compound and thus its identity with *iso*borneol is tentative only.

## EXPERIMENTAL

### Collection of Plant Material and Isolation of Volatile Oils.

Fresh foliage and terminal branchlets (400g) were steam distilled with cohobation in an all-glass apparatus (Hughes, 1970) to yield pale yellow oils (Table 2).

### Identification of Oil Components.

Analytical g.l.c. was conducted on a Perkin Elmer 900 gas chromatograph using 15m by 0.5m i.d. stainless steel FFAP, SE-30 and DC 550 S.C.O.T. columns with He as carrier gas. Individual components were identified by their retention times and by co-injection with authentic compounds. A Hewlett Packard 3370A integrator was used to determine % compositions.

Mass spectra were determined using a Pye 104 gas chromatograph equipped with 100m by 0.77mm i.d. OV-17 W.C.O.T. columns interfaced to a AEI MS 30 instrument via a 0.1mm thick silicone rubber membrane separator. The mass spectrometer was operated at 70 eV with the ion source at 200$^{o}$. The spectra were handled by a AEI DS 30 data handling system which produced standard bar graphs for direct comparison with published spectra.

TABLE 1.
% Composition+

| Peak* | Compound | *M. adnata* | *M. thymifolia* | *M. nodosa* Yarramundi | *M. nodosa* Doyalson |
|---|---|---|---|---|---|
| 1 | *iso*valeric aldehyde | - | 0.9 | tr. | 0.2 |
| 2 | α-thujene | 2.0 | tr. | 0.3 | 1.9 |
| 3 | α-pinene | 6.7 | 84.2 | 6.3 | 29.6 |
| 4 | Sabinene | - | - | 0.6 | 0.4 |
| 5 | β-pinene | 5.3 | - | 10.7 | 1.4 |
| 6 | myrcene | 1.2 | - | 1.4 | 0.9 |
| 7 | α-phellandrene | - | - | 0.2 | 0.3 |
| 8 | α-terpinene | - | - | 1.7 | 1.8 |
| 9 | limonene | 7.7 | 1.4 | 4.6 | 4.0 |
| 10 | 1,8-cineole | 66.0 | 1.0 | 54.7 | 40.5 |
| 11 | γ-terpinene | 0.3 | 0.8 | 4.0 | 4.6 |
| 12 | *p*-cymene | 0.9 | 0.6 | 0.2 | 0.6 |
| 13 | terpinolene | tr. | 0.1 | 0.6 | 0.7 |
| 14 | unknown | - | tr. | 0.3 | - |
| 15 | linalool | 0.3 | 1.1 | 0.3 | 0.4 |
| 16 | unknown | - | - | 0.1 | tr. |
| 17 | terpinen-4-ol | 1.2 | 0.4 | 4.8 | 7.6 |
| 18 | β-caryophyllene | 0.2 | 0.2 | 0.2 | tr. |
| 19 | unknown | tr. | 1.6 | - | - |
| 20 | unknown | - | 0.3 | - | - |
| 21 | *iso*borneol | 0.3 | 0.3 | 0.3 | 0.3 |
| 22 | α-terpineol | 6.4 | 1.3 | 5.9 | 4.4 |
| 23 | terpenyl acetate | - | - | 0.1 | 0.2 |
| 24 | unknown | 0.6 | - | - | - |
| 25 | unknown | - | 0.9 | - | - |
| 26 | aromadendrene | - | 2.8 | 1.1 | tr. |
| 27 | sesquiterpene | - | - | 0.2 | tr. |
| 28 | unknown | 0.2 | - | 0.1 | tr. |
| 29 | globulol | - | 0.8 | 0.5 | tr. |
| 30 | unknown | - | 0.3 | 0.3 | tr. |
| 31 | viridiflorol | 0.6 | 0.8 | 0.3 | tr. |
| 32 | unknown | - | 0.1 | - | - |

*Peaks 1-3 refer to a DC550 coated S.C.O.T. column; peaks 14-32 refer to a FFAP coated S.C.O.T. column.
+tr.: $< 0.1\%$

TABLE 2.

| Species | Locality | Voucher No* | Oil Yield V/W | $n_D^{20}$ | $\alpha_D^{20}$ | $d_{20}^{4}$ |
|---|---|---|---|---|---|---|
| *M. adnata* | Goonoo Goonoo State Forest | 73-104 | 1.4% | 1.4648 | $+1.2^o$ | 0.9107 |
| *M. thymifolia* | Doyalson | 77-009 | 0.7% | 1.4713 | $+34.0^o$ | 0.8778 |
| *M. nodosa* | Yarramundi | 75-077 | 1.7% | 1.4671 | $+8.4^o$ | 0.9041 |
| *M. nodosa* | Doyalson | 77-008 | 1.3% | 1.4672 | $+9.2^o$ | 0.8960 |

*Museum of Applied Arts and Sciences Herbarium numbers.

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Journal and Proceedings, Royal Society of New South Wales, Vol. 112, pp. 159, 1979

# ERRATA

## A Reappraisal of the Late Devonian Bective Unconformity

T. G. Russell

(Journal and Proceedings, Royal Society of New South Wales, Vol. 112, pp. 63-69, 1979)

Pages 64 and 65 are reversed. Page 65 is the second page of the Article, and page 64 is the third.

Page 64, Right Hand Column
text line 31. underlined section missing. "resulted in sandier "Lowana-like" Eungai lithologies being developed in these areas. The Eungai Mudstone does become ........"

text line 36. tham = them

text line 57. argu = argue

Page 66, Left Hand Column
text line 18, underlined section missing. "Conglomerate is obscured by Tertiary basalt cover and thus the erosional slope shown can only be conjectural. Furthermore, where the Keepit Conglomerate is exposed, no evidence of erosional ......"

text line 42. Offenber = Offenberg

text line 49. horixons = horizons

Right Hand Column

text line 5. contact = contacts

text line 5. "with the doubtful"

Caption, Fig. 2, line 3. "thin to medium"

Page 67, Left Hand Column

text line 14. sbruptly = abruptly

text line 39. orginally = originally

Caption, Fig. 3, line 2. conglomerage = conglomerate

Right Hand Column

text line 10. underlined section missing. "those exhibiting the first type of disconformity, and to the west of those possessing a conformable ......"

Page 68, Left Hand Column

text line 3. "basin edge disconformity"

text line 7. equivokal = equivocal

References:

| | |
|---|---|
| Cawood | Ordivician = Ordovician |
| Crook, 1959a | Twmworth = Tamworth |
| Manser | 1:1000,000 = 1:100,000 |
| Pickett | form = from the |
| White, 1965 | 1:111,000 = 1:100,000 |

The Honorary Editor, on behalf of the Royal Society, apologises for the printing errors which occurred during processing of this manuscript.

JOURNAL AND PROCEEDINGS

OF THE

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**Dates of publication**
Parts 1 and 2: 12th October, 1979
Parts 3 and 4: 20th December, 1979

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## VOLUME 112, PART 4



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# Journal and Proceedings of the Royal Society of New South Wales

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# THE ROYAL SOCIETY OF NEW SOUTH WALES



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## VOLUME 113, PART 1

Journal and Proceedings, Royal Society of New South Wales, Vol. 113, pp. 1-6, 1980

# Precise Observations of Minor Planets at Sydney Observatory During 1979

N. R. Lomb

ABSTRACT. Positions of 1 Ceres, 3 Juno, 4 Vesta, 6 Hebe, 7 Iris, 40 Harmonia, 51 Nemausa, 532 Herculina and 704 Interamnia obtained with the 23 cm camera are given.

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1979 are given here. The methods of observation were described in the first paper (Robertson 1958). All the plates were taken with the 23 cm camera (scale 116" to the millimetre). Four exposures were taken on each plate, except on some plates of 51 Nemausa, 532 Herculina and 704 Interamnia. The number of exposures on each plate is indicated in Table 1. On some plates of the two brightest objects, 1 Ceres and 4 Vesta, an objective grating was used to give side images dispersed in right ascension; on these plates the side images of the minor planets were measured.

In Table 1 are given the means of the positions for all the exposures using all six reference stars at the mean of the exposure times. The result for the first pair of images was compared with that for the last two by adding the motion computed from the ephemeris for the plates with four exposures. The r.m.s. differences were $0\overset{s}{.}014 \sec \delta$ in right ascension and 0".27 in declination.

No correction has been applied for aberration, light time or parallax, but the factors give the parallax correction when divided by the distance. The column headed "O-C" gives the differences between the measured positions (corrected for parallax) and the position computed from the ephemerides supplied by the Institute for Theoretical Astronomy in Leningrad. The ephemeris for 51 Nemausa was obtained from L.K. Kristensen (University of Aarhus, Denmark).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table 2 gives for each observation the positions of the reference stars and the six star dependences. The reference star positions were converted to standard coordinates for the calculation of six star dependences. The columns headed "R.A." and "Dec." give the seconds of time and arc with the proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Stars" gives the Durchmusterung number taken from either the AGK3 or SAO catalogue. The first column gives a serial number which cross-references Table 1 and Table 2 and also the catalogue from which the reference stars were taken.

All plates were reduced by both the methods of dependences and by first order plate constants using the same six reference stars. Equal results were obtained in each case, as could be expected due to the formal identity of the two methods. The r.m.s. residuals of the reference stars were obtained by taking for each star the mean residual from the plate constants fitted to the first and last pairs of images, summing the squares of these residuals in right ascension and declination for all stars on all plates with four exposures and dividing the result by the appropriate number of degrees of freedom. For AGK3 stars the r.m.s. residual was 0".40 (9 plates) while for SAO stars it was 0".71 (40 plates).

Using six star dependences instead of two sets of three star dependences, as had been employed in reducing observations from years previous to 1978, has the disadvantage that a direct measure of the uncertainties in the measured positions is no longer available and the uncertainties have to be found by indirect means. It is easiest to do this using the formalism of the method of dependences. The standard coordinate of the minor planet ($\xi$) is given by

$$\xi = \sum D_i \xi_i + x - \sum D_i x_i$$

where x is the measured coordinate of the planet, the $\xi_i$ and the $x_i$ are the standard and the measured coordinates of the reference stars respectively and the $D_i$ are the dependences. Thus, the variance of the standard coordinate of the minor planet ($\sigma^2(\xi)$) is given by

$$\sigma^2(\xi) = \sigma^2(\xi_i)\sum D_i^{\,2} + \sigma^2(x) + \sigma^2(x_i)\sum D_i^{\,2}$$

where $\sigma^2(x)$ is the variance of the measured coordinate of the planet and $\sigma^2(\xi_i)$ and $\sigma^2(x_i)$ are the variances of the standard and the measured coordinates of the reference stars. The first term can be obtained to a good approximation from the values given above for the r.m.s. residuals of the AGK3 and the SAO stars, together with the mean value of $\sum D_i^{\,2}$ which is 0.178 for the plates with four exposures. The sum of the second and third terms can be calculated from the values given above for the r.m.s. differences between the results for the first and last pair of images, by dividing their variances by two since they are differences and a further two when considering plates with four exposures. The standard errors calculated in this way are listed in Table 3.

The plates were measured by Mrs J. Close, Miss D. Teale and Miss J. Westaway. The observers at the telescope were D.S. King (K), N.R. Lomb (L), W.H. Robertson (R) and K.P. Sims (S).

TABLE 1

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | No. of Exp. | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 Ceres 1979 U.T. | | | | | | | | |
| 1656 | Aug. 16.74670 | 01 31 07.350 | -04 58 08.63 | +0.012 | -4.24 | -0.020 | -0.20 | 4 | L |
| 1657 | Aug. 21.74971 | 01 31 09.440 | -05 15 59.82 | +0.063 | -4.21 | -0.032 | +0.06 | 4 | S |
| 1658 | Sep. 12.67118 | 01 24 34.709 | -06 59 48.54 | +0.020 | -3.97 | -0.012 | -0.03 | 4 | L |
| 1659 | Sep. 17.63840 | 01 21 39.144 | -07 26 20.85 | -0.033 | -3.91 | +0.007 | +0.35 | 4 | R |
| 1660 | Oct. 08.56872 | 01 05 25.920 | -09 06 17.34 | -0.036 | -3.68 | +0.003 | +1.70 | 4 | K |
| 1661 | Oct. 30.50895 | 00 47 44.605 | -09 49 21.07 | +0.003 | -3.58 | -0.074 | +0.32 | 4 | S |
| 1662 | Nov. 16.46248 | 00 38 48.872 | -09 21 16.29 | +0.022 | -3.64 | -0.063 | +0.25 | 4 | S |
| 1663 | Nov. 20.45870 | 00 37 36.289 | -09 07 09.34 | +0.047 | -3.68 | -0.075 | +0.16 | 4 | L |
| | 3 Juno 1979 U.T. | | | | | | | | |
| 1664 | Dec. 17.67029 | 07 42 29.230 | +00 26 18.26 | +0.019 | -4.92 | -0.041 | -0.74 | 4 | K |
| | 4 Vesta 1979 U.T. | | | | | | | | |
| 1665 | Oct. 30.58469 | 02 47 46.402 | +05 05 59.96 | -0.020 | -5.52 | +0.054 | +0.45 | 4 | S |
| 1666 | Nov. 22.52022 | 02 25 42.593 | +04 13 24.31 | +0.022 | -5.41 | +0.035 | +0.69 | 4 | L |
| 1667 | Dec. 10.46779 | 02 14 38.895 | +04 30 33.80 | +0.035 | -5.45 | +0.049 | -0.10 | 4 | S |
| 1668 | Dec. 17.43898 | 02 12 38.881 | +04 51 26.23 | +0.010 | -5.49 | +0.029 | +0.64 | 4 | L |
| | 6 Hebe 1979 U.T. | | | | | | | | |
| 1669 | Mar. 26.76605 | 16 39 27.798 | -03 17 11.98 | +0.003 | -4.44 | -0.007 | +0.30 | 4 | K |
| 1670 | Apr. 03.74979 | 16 40 38.666 | -02 29 45.06 | +0.017 | -4.54 | -0.035 | +0.02 | 4 | L |
| 1671 | May 28.58840 | 16 09 11.552 | +02 01 07.38 | +0.050 | -5.11 | -0.002 | -0.42 | 4 | L |
| 1672 | June 25.49054 | 15 46 04.189 | +01 10 59.49 | +0.033 | -5.01 | +0.003 | +0.37 | 4 | K |
| 1673 | July 02.47842 | 15 42 28.169 | +00 34 18.57 | +0.062 | -4.93 | -0.025 | -0.04 | 4 | L |
| 1674 | July 20.41539 | 15 38 49.136 | -01 30 54.04 | +0.028 | -4.66 | -0.011 | -0.08 | 4 | L |
| 1675 | July 23.40400 | 15 39 00.522 | -01 55 00.55 | +0.017 | -4.61 | +0.006 | -0.46 | 4 | K |
| 1676 | Aug. 07.35960 | 15 43 15.200 | -04 04 01.07 | -0.002 | -4.33 | +0.005 | -0.64 | 4 | S |
| | 7 Iris 1979 U.T. | | | | | | | | |
| 1677 | Mar. 26.74338 | 16 08 08.276 | -24 44 07.73 | -0.001 | -1.35 | +0.020 | -0.11 | 4 | K |
| 1678 | Apr. 05.73484 | 16 06 45.211 | -24 41 08.71 | +0.066 | -1.38 | -0.096 | -0.26 | 4 | L |
| 1679 | May 30.54840 | 15 23 08.209 | -21 37 29.51 | +0.045 | -1.83 | -0.034 | -0.91 | 4 | L |
| 1680 | June 06.50476 | 15 17 00.580 | -21 01 56.98 | -0.022 | -1.91 | -0.097 | -0.54 | 4 | R |
| 1681 | June 14.48828 | 15 11 03.274 | -20 23 22.60 | +0.009 | -2.00 | -0.033 | -0.65 | 4 | R |
| 1682 | June 25.46220 | 15 05 11.673 | -19 37 48.69 | +0.035 | -2.12 | -0.034 | -0.25 | 4 | S |
| 1683 | July 03.43438 | 15 02 49.658 | -19 12 08.51 | +0.021 | -2.18 | -0.051 | +0.30 | 4 | R |
| 1684 | July 16.41561 | 15 02 25.185 | -18 45 40.69 | +0.076 | -2.27 | -0.100 | +0.20 | 4 | S |
| 1685 | July 23.37708 | 15 03 52.872 | -18 39 16.67 | +0.010 | -2.26 | -0.111 | -0.32 | 4 | K |
| 1686 | July 30.36991 | 15 06 27.358 | -18 37 58.48 | +0.042 | -2.27 | -0.077 | +0.11 | 4 | S |
| | 40 Harmonia 1979 U.T. | | | | | | | | |
| 1687 | Mar. 06.72180 | 14 23 01.124 | -07 47 45.81 | -0.011 | -3.82 | +0.003 | -0.15 | 4 | R |
| 1688 | Mar. 27.65910 | 14 16 12.102 | -06 37 46.78 | -0.013 | -3.98 | -0.022 | +0.42 | 4 | K |
| 1689 | Apr. 03.65414 | 14 11 11.319 | -06 04 50.43 | +0.042 | -4.05 | -0.008 | +0.40 | 4 | L |
| 1690 | May 17.49310 | 13 32 09.469 | -03 18 51.88 | -0.001 | -4.42 | +0.037 | -0.78 | 4 | S |
| 1691 | June 25.40765 | 13 28 55.831 | -04 55 54.31 | +0.070 | -4.21 | -0.062 | -0.35 | 4 | S |
| 1692 | July 11.36089 | 13 38 45.952 | -06 35 33.78 | +0.040 | -3.98 | -0.010 | +0.17 | 4 | K |

TABLE 1 (Cont.)

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O - C s | " | No. of Exp. | |
|---|---|---|---|---|---|---|---|---|---|
| | 51 Nemausa 1979 U.T. | | | | | | | | |
| 1693 | July 03.67742 | 20 59 33.392 | -03 51 37.21 | +0.008 | -4.38 | +0.018 | +0.24 | 4 | L |
| 1694 | July 17.63395 | 20 50 13.007 | -04 30 35.16 | +0.011 | -4.30 | +0.021 | +0.07 | 4 | R |
| 1695 | July 24.61797 | 20 44 19.098 | -05 04 40.07 | +0.034 | -4.22 | -0.048 | -0.42 | 4 | S |
| 1696 | Aug. 13.54931 | 20 26 39.116 | -07 20 50.93 | +0.028 | -3.91 | -0.068 | +0.54 | 4 | L |
| 1697 | Oct. 09.38689 | 20 18 48.750 | -13 15 32.33 | +0.024 | -3.08 | +0.112 | -0.48 | 2 | R |
| | 532 Herculina 1979 U.T. | | | | | | | | |
| 1698 | July 18.69368 | 22 32 06.699 | -22 38 36.30 | -0.015 | -1.71 | -0.013 | +0.54 | 2 | R |
| 1699 | July 23.70898 | 22 29 58.294 | -23 22 18.41 | +0.086 | -1.63 | -0.078 | +0.18 | 2 | S |
| 1700 | Aug. 02.66703 | 22 24 14.163 | -24 51 33.95 | +0.051 | -1.38 | -0.003 | +0.40 | 2 | K |
| 1701 | Aug. 15.61961 | 22 14 30.479 | -26 43 02.36 | +0.034 | -1.09 | +0.054 | -0.33 | 2 | L |
| 1702 | Aug. 21.60406 | 22 09 30.827 | -27 28 57.27 | +0.050 | -0.99 | +0.001 | -0.31 | 4 | S |
| 1703 | Sep. 12.54209 | 21 52 08.726 | -29 24 59.43 | +0.086 | -0.72 | -0.062 | +0.88 | 2 | L |
| 1704 | Oct. 08.44070 | 21 41 24.897 | -29 43 03.17 | +0.005 | -0.63 | -0.051 | +0.20 | 2 | S |
| | 704 Interamnia 1979 U.T. | | | | | | | | |
| 1705 | June 07.75422 | 21 11 35.742 | -08 30 44.76 | 0.000 | -3.75 | +0.010 | +0.11 | 4 | R |
| 1706 | June 25.70719 | 21 09 09.140 | -06 24 43.10 | +0.011 | -4.04 | +0.052 | +0.60 | 4 | K |
| 1707 | July 02.68402 | 21 06 10.247 | -05 42 16.33 | +0.005 | -4.14 | +0.052 | +0.64 | 4 | L |
| 1708 | July 16.64973 | 20 57 09.532 | -04 31 57.25 | +0.037 | -4.30 | +0.031 | +0.37 | 4 | R |
| 1709 | July 23.61243 | 20 51 27.430 | -04 05 19.04 | -0.007 | -4.35 | +0.063 | +0.47 | 4 | S |
| 1710 | Aug. 01.57542 | 20 43 26.673 | -03 39 58.43 | -0.028 | -4.41 | +0.037 | +0.31 | 2 | K |
| 1711 | Aug. 02.59160 | 20 42 30.880 | -03 37 44.31 | +0.032 | -4.41 | +0.071 | +0.03 | 2 | K |
| 1712 | Aug. 14.54500 | 20 31 47.224 | -03 20 29.48 | +0.012 | -4.45 | -0.002 | +0.15 | 4 | L |
| 1713 | Oct. 08.40102 | 20 15 58.272 | -03 47 15.66 | +0.065 | -4.40 | +0.025 | +0.71 | 4 | S |

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | | Depend. | R.A. | Dec. | No. | Stars | | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1656 | - 4 | 218 | 0.195774 | 09.748 | 42.84 | 1660 | - 8 | 185 | 0.168564 | 42.247 | 05.19 |
| SAO | - 6 | 284 | 0.164562 | 37.145 | 02.80 | SAO | - 9 | 213 | 0.166869 | 49.688 | 00.25 |
| | - 6 | 291 | 0.148899 | 39.451 | 54.46 | | -10 | 235 | 0.163219 | 17.289 | 46.52 |
| | - 4 | 234 | 0.190820 | 57.895 | 12.06 | | - 8 | 201 | 0.170176 | 44.433 | 08.43 |
| | - 5 | 287 | 0.164588 | 10.867 | 26.63 | | -10 | 247 | 0.164111 | 52.081 | 43.20 |
| | - 6 | 306 | 0.135357 | 30.018 | 01.14 | | - 9 | 239 | 0.167060 | 11.490 | 29.85 |
| 1657 | - 4 | 218 | 0.245608 | 09.748 | 42.84 | 1661 | -10 | 159 | 0.173725 | 59.488 | 51.25 |
| SAO | - 6 | 284 | 0.197958 | 37.145 | 02.80 | SAO | -10 | 161 | 0.209124 | 32.256 | 03.54 |
| | - 6 | 291 | 0.164608 | 39.451 | 54.46 | | - 9 | 153 | 0.072748 | 55.948 | 25.94 |
| | - 5 | 287 | 0.157660 | 10.867 | 26.63 | | - 9 | 171 | 0.123922 | 05.735 | 24.10 |
| | - 6 | 306 | 0.113474 | 30.018 | 01.14 | | -10 | 181 | 0.242361 | 36.023 | 32.77 |
| | - 5 | 294 | 0.120693 | 06.287 | 32.02 | | -10 | 183 | 0.178121 | 29.237 | 37.12 |
| 1658 | - 7 | 226 | 0.191819 | 43.837 | 08.24 | 1662 | - 9 | 117 | 0.214023 | 05.572 | 53.53 |
| SAO | - 7 | 227 | 0.188425 | 45.631 | 06.24 | SAO | - 8 | 110 | 0.123220 | 12.392 | 47.57 |
| | - 7 | 232 | 0.166388 | 30.266 | 29.42 | | -10 | 133 | 0.251843 | 22.005 | 04.24 |
| | - 8 | 250 | 0.169960 | 58.242 | 12.20 | | - 8 | 119 | 0.113321 | 18.940 | 46.68 |
| | - 7 | 239 | 0.145948 | 35.840 | 22.95 | | -10 | 150 | 0.199696 | 41.237 | 30.39 |
| | - 7 | 240 | 0.137460 | 06.704 | 27.81 | | - 9 | 150 | 0.097897 | 41.155 | 17.01 |
| 1659 | - 7 | 212 | 0.148473 | 30.017 | 06.95 | 1663 | - 9 | 113 | 0.168333 | 49.817 | 44.27 |
| SAO | - 7 | 215 | 0.175070 | 38.508 | 36.45 | SAO | - 9 | 117 | 0.169304 | 05.572 | 53.53 |
| | - 8 | 233 | 0.111127 | 54.698 | 48.27 | | - 8 | 113 | 0.163792 | 27.806 | 47.23 |
| | - 7 | 227 | 0.214708 | 45.631 | 06.24 | | -10 | 133 | 0.169599 | 22.005 | 04.24 |
| | - 9 | 276 | 0.146568 | 17.329 | 47.59 | | - 8 | 119 | 0.163073 | 18.940 | 46.68 |
| | - 8 | 250 | 0.204055 | 58.242 | 12.20 | | -10 | 150 | 0.165898 | 41.237 | 30.39 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | Depend. | R.A. | Dec. | No. | Stars | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1664 | + 0 2046 | 0.222197 | 32.523 | 28.05 | 1675 | - 1 3074 | 0.175920 | 06.398 | 28.65 |
| AGK3 | + 1 1890 | 0.189878 | 59.440 | 02.20 | SAO | - 2 4031 | 0.174821 | 43.845 | 01.19 |
| | + 0 2064 | 0.185091 | 23.596 | 48.95 | | - 2 4034 | 0.171517 | 48.490 | 30.59 |
| | + 0 2071A | 0.159670 | 08.127 | 34.06 | | - 0 3001 | 0.159640 | 46.772 | 02.55 |
| | + 1 1905 | 0.129239 | 35.107 | 34.04 | | - 1 3085 | 0.158607 | 38.215 | 30.00 |
| | + 0 2097 | 0.113925 | 11.265 | 20.08 | | - 1 3089 | 0.159495 | 26.111 | 05.48 |
| 1665 | + 4 439 | 0.144747 | 36.532 | 00.43 | 1676 | - 3 3818 | 0.182501 | 47.964 | 53.11 |
| AGK3 | + 5 395 | 0.186439 | 59.651 | 18.15 | SAO | - 4 3958 | 0.181837 | 01.597 | 31.63 |
| | + 3 388 | 0.117649 | 36.413 | 02.65 | | - 2 4040 | 0.176219 | 44.136 | 21.09 |
| | + 3 395 | 0.133267 | 46.859 | 02.51 | | - 4 3975 | 0.159614 | 43.768 | 55.55 |
| | + 5 403 | 0.216919 | 59.513 | 06.54 | | - 4 3977 | 0.154385 | 33.566 | 59.33 |
| | + 4 456 | 0.200979 | 07.197 | 22.51 | | - 3 3832 | 0.145444 | 53.322 | 06.78 |
| 1666 | + 3 331 | 0.091303 | 00.952 | 53.41 | 1677 | -25 11379 | 0.232728 | 42.156 | 42.60 |
| AGK3 | + 2 371 | 0.065083 | 46.059 | 03.63 | SAO | -24 12567 | 0.223086 | 52.765 | 45.98 |
| | + 4 393 | 0.178096 | 48.870 | 44.27 | | -25 11425 | 0.172035 | 56.058 | 48.11 |
| | + 4 401 | 0.269141 | 57.335 | 08.18 | | -23 12769 | 0.151601 | 09.865 | 37.86 |
| | + 2 384 | 0.142349 | 27.078 | 39.74 | | -23 12786 | 0.124093 | 47.602 | 46.95 |
| | + 3 348 | 0.254028 | 08.689 | 56.35 | | -24 12642 | 0.096457 | 45.282 | 49.55 |
| 1667 | + 4 366 | 0.153802 | 38.923 | 00.12 | 1678 | -24 12534 | 0.188581 | 24.872 | 09.73 |
| AGK3 | + 3 309 | 0.155760 | 33.046 | 32.74 | SAO | -23 12717 | 0.153535 | 30.139 | 04.05 |
| | + 4 372 | 0.161835 | 41.733 | 40.56 | | -25 11373 | 0.201643 | 15.054 | 17.18 |
| | + 3 325 | 0.173646 | 00.471 | 48.99 | | -25 11425 | 0.179847 | 56.058 | 48.11 |
| | + 4 382 | 0.177603 | 20.680 | 01.56 | | -23 12769 | 0.132386 | 09.865 | 37.86 |
| | + 4 383 | 0.177353 | 36.564 | 02.91 | | -24 12622 | 0.144009 | 40.627 | 52.37 |
| 1668 | + 4 365 | 0.220122 | 32.321 | 21.22 | 1679 | -21 4098 | 0.204805 | 24.048 | 41.91 |
| AGK3 | + 4 366 | 0.250047 | 38.886 | 59.22 | SAO | -21 4101 | 0.192071 | 58.424 | 30.65 |
| | + 4 374 | 0.145020 | 10.480 | 08.44 | | -22 10999 | 0.156055 | 49.303 | 53.75 |
| | + 3 313 | 0.183221 | 49.696 | 41.39 | | -20 4237 | 0.165691 | 12.759 | 03.59 |
| | + 4 379 | 0.115279 | 45.632 | 20.32 | | -21 4117 | 0.141782 | 32.384 | 09.02 |
| | + 4 383 | 0.086311 | 36.513 | 03.82 | | -21 4120 | 0.139596 | 37.739 | 29.39 |
| 1669 | - 3 3973 | 0.169275 | 18.455 | 34.16 | 1680 | -20 4189 | 0.144932 | 09.330 | 28.00 |
| SAO | - 2 4227 | 0.185607 | 13.909 | 38.43 | SAO | -21 4072 | 0.174232 | 50.326 | 21.64 |
| | - 3 3978 | 0.149496 | 44.135 | 09.03 | | -20 4204 | 0.146679 | 51.635 | 10.19 |
| | - 2 4235 | 0.182033 | 20.169 | 20.47 | | -21 4086 | 0.200058 | 30.638 | 50.89 |
| | - 2 4239 | 0.168728 | 52.894 | 24.61 | | -20 4217 | 0.173586 | 30.272 | 12.84 |
| | - 3 3988 | 0.144862 | 45.519 | 57.09 | | -20 4221 | 0.160513 | 40.529 | 05.42 |
| 1670 | - 2 4227 | 0.324579 | 13.909 | 38.43 | 1681 | -20 4163 | 0.198743 | 37.783 | 03.32 |
| SAO | - 1 3228 | 0.227841 | 51.752 | 41.38 | SAO | -20 4170 | 0.179153 | 42.478 | 36.20 |
| | - 3 3991 | 0.229148 | 26.640 | 22.15 | | -19 4052 | 0.193503 | 04.602 | 11.39 |
| | - 1 3244 | 0.056198 | 49.299 | 15.68 | | -19 4060 | 0.158896 | 38.097 | 54.37 |
| | - 1 3248 | 0.061142 | 26.984 | 39.35 | | -20 4186 | 0.139069 | 53.688 | 18.16 |
| | - 2 4254 | 0.101091 | 51.249 | 05.69 | | -20 4189 | 0.130636 | 09.330 | 28.00 |
| 1671 | + 2 3053 | 0.156088 | 16.664 | 39.22 | 1682 | -19 4016 | 0.225521 | 26.606 | 39.69 |
| AGK3 | + 2 3056 | 0.090661 | 13.151 | 29.24 | SAO | -19 4019 | 0.191911 | 57.038 | 19.37 |
| | + 1 3171 | 0.249291 | 06.197 | 42.17 | | -18 3982 | 0.187057 | 47.143 | 08.39 |
| | + 3 3140 | 0.085537 | 34.070 | 44.14 | | -19 4033 | 0.144235 | 08.950 | 44.70 |
| | + 1 3179 | 0.275191 | 15.630 | 54.10 | | -18 3991 | 0.157490 | 22.809 | 24.75 |
| | + 3 3152 | 0.143232 | 54.857 | 36.74 | | -19 4052 | 0.093786 | 04.602 | 11.39 |
| 1672 | + 1 3126 | 0.196180 | 19.465 | 50.64 | 1683 | -19 4003 | 0.207077 | 10.661 | 36.23 |
| AGK3 | + 1 3127P | 0.207916 | 30.231 | 09.64 | SAO | -18 3959 | 0.182132 | 54.293 | 16.18 |
| | + 0 3405 | 0.147878 | 26.313 | 42.23 | | -18 3965 | 0.157838 | 04.297 | 46.78 |
| | + 2 3005 | 0.174796 | 27.693 | 22.61 | | -19 4030 | 0.166805 | 26.480 | 30.65 |
| | + 1 3137 | 0.146473 | 50.658 | 14.50 | | -18 3982 | 0.153148 | 47.143 | 08.39 |
| | + 0 3415 | 0.126757 | 58.307 | 57.78 | | -17 4260 | 0.133001 | 40.660 | 32.35 |
| 1673 | - 0 3000 | 0.134804 | 18.288 | 14.80 | 1684 | -18 3959 | 0.272261 | 54.293 | 16.18 |
| AGK3 | + 1 3120 | 0.227158 | 27.707 | 21.10 | SAO | -17 4240 | 0.221036 | 54.904 | 54.21 |
| | + 1 3126 | 0.194391 | 19.465 | 50.64 | | -17 4249 | 0.132750 | 28.299 | 09.50 |
| | + 0 3398 | 0.134433 | 27.217 | 01.05 | | -19 4030 | 0.182429 | 26.480 | 30.65 |
| | + 1 3129 | 0.174076 | 10.985 | 39.84 | | -18 3982 | 0.138822 | 47.143 | 08.39 |
| | + 0 3400 | 0.135138 | 35.115 | 10.43 | | -17 4259 | 0.052702 | 30.536 | 29.31 |
| 1674 | - 1 3074 | 0.181137 | 06.367 | 28.29 | 1685 | -18 3959 | 0.164680 | 54.293 | 16.18 |
| AGK3 | - 0 2993 | 0.135855 | 56.350 | 13.95 | SAO | -17 4240 | 0.134607 | 54.904 | 54.21 |
| | - 1 3079 | 0.214573 | 38.155 | 03.12 | | -17 4249 | 0.130958 | 28.299 | 09.50 |
| | - 0 2999 | 0.118528 | 06.651 | 16.01 | | -19 4030 | 0.215350 | 26.480 | 30.65 |
| | - 1 3087 | 0.195631 | 07.917 | 55.19 | | -17 4259 | 0.160085 | 30.536 | 29.31 |
| | - 0 3003 | 0.154276 | 08.828 | 30.82 | | -18 3989 | 0.194321 | 03.508 | 35.29 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | Depend. | R.A. | Dec. | No. | Stars | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1686 | -18 3965 | 0.135902 | 04.296 | 46.78 | 1697 | -12 5687 | 0.129168 | 10.278 | 48.29 |
| SAO | -18 3973 | 0.164474 | 24.863 | 00.50 | SAO | -13 5636 | 0.142828 | 53.741 | 21.30 |
| | -19 4034 | 0.205204 | 20.667 | 59.04 | | -14 5718 | 0.160908 | 56.617 | 18.91 |
| | -17 4259 | 0.140488 | 30.537 | 29.32 | | -12 5702 | 0.165456 | 48.726 | 20.66 |
| | -17 4272 | 0.163405 | 14.235 | 23.79 | | -13 5656 | 0.197324 | 35.390 | 47.19 |
| | -18 3999 | 0.190526 | 53.674 | 51.03 | | -14 5733 | 0.204316 | 48.082 | 55.17 |
| 1687 | - 7 3831 | 0.148000 | 23.238 | 49.42 | 1698 | -23 17474 | 0.196864 | 50.472 | 01.22 |
| SAO | - 6 3983 | 0.159664 | 51.716 | 54.73 | SAO | -22 15933 | 0.159877 | 00.354 | 34.56 |
| | - 8 3771 | 0.150561 | 58.209 | 02.30 | | -23 17498 | 0.213357 | 10.993 | 23.80 |
| | - 6 4000 | 0.185008 | 42.229 | 09.68 | | -22 15959 | 0.127587 | 45.403 | 20.26 |
| | - 8 3781 | 0.166991 | 30.242 | 01.79 | | -23 17523 | 0.175141 | 14.542 | 16.21 |
| | - 7 3854 | 0.189775 | 29.160 | 34.78 | | -22 15986 | 0.127174 | 59.255 | 02.25 |
| 1688 | - 6 3955 | 0.080971 | 03.528 | 00.70 | 1699 | -23 17458 | 0.142017 | 33.693 | 17.96 |
| SAO | - 6 3957 | 0.150564 | 22.049 | 47.53 | SAO | -24 17198 | 0.147286 | 50.039 | 48.58 |
| | - 5 3849 | 0.285600 | 00.232 | 46.85 | | -22 15939 | 0.170087 | 20.827 | 14.18 |
| | - 7 3818 | 0.093991 | 40.414 | 08.17 | | -24 17222 | 0.170452 | 05.436 | 28.36 |
| | - 6 3977 | 0.150946 | 00.394 | 54.68 | | -23 17496 | 0.185573 | 37.421 | 38.72 |
| | - 6 3981 | 0.237928 | 10.339 | 33.92 | | -23 17498 | 0.184585 | 10.993 | 23.80 |
| 1689 | - 6 3941 | 0.125567 | 33.163 | 37.25 | 1700 | -25 15896 | 0.159354 | 54.143 | 41.93 |
| SAO | - 6 3944 | 0.132537 | 18.825 | 27.34 | SAO | -24 17154 | 0.178705 | 11.926 | 31.15 |
| | - 5 3827 | 0.155505 | 23.723 | 20.95 | | -26 16125 | 0.146432 | 16.797 | 49.12 |
| | - 4 3645 | 0.182395 | 59.853 | 39.40 | | -24 17182 | 0.188498 | 27.228 | 53.12 |
| | - 6 3957 | 0.192849 | 22.049 | 47.53 | | -26 16165 | 0.154342 | 17.095 | 40.76 |
| | - 5 3849 | 0.211148 | 00.232 | 46.85 | | -25 15967 | 0.172669 | 59.936 | 35.99 |
| 1690 | - 2 3703 | 0.190157 | 40.585 | 31.94 | 1701 | -26 16032 | 0.155286 | 06.853 | 50.08 |
| SAO | - 3 3494 | 0.180148 | 35.469 | 03.91 | SAO | -28 17648 | 0.103336 | 49.960 | 26.30 |
| | - 2 3708 | 0.178226 | 26.662 | 19.30 | | -26 16066 | 0.203224 | 35.511 | 39.13 |
| | - 3 3501 | 0.157891 | 56.413 | 06.09 | | -27 15850 | 0.152249 | 35.401 | 43.51 |
| | - 2 3711 | 0.158147 | 43.681 | 03.57 | | -27 15853 | 0.177631 | 09.231 | 57.04 |
| | - 2 3716 | 0.135431 | 55.158 | 09.94 | | -26 16086 | 0.208274 | 20.074 | 36.49 |
| 1691 | - 4 3485 | 0.170644 | 03.338 | 43.19 | 1702 | -27 15789 | 0.232132 | 07.676 | 29.02 |
| SAO | - 4 3494 | 0.168292 | 07.340 | 53.60 | SAO | -28 17627 | 0.177630 | 30.380 | 18.46 |
| | - 5 3713 | 0.167172 | 15.736 | 27.13 | | -27 15814 | 0.213423 | 02.246 | 22.69 |
| | - 3 3491 | 0.165103 | 46.879 | 35.71 | | -28 17646 | 0.135285 | 19.188 | 10.26 |
| | - 4 3506 | 0.165132 | 53.931 | 18.96 | | -26 16051 | 0.153426 | 22.959 | 32.06 |
| | - 4 3508 | 0.163657 | 38.873 | 05.87 | | -27 15850 | 0.088103 | 35.401 | 43.51 |
| 1692 | - 6 3853 | 0.194908 | 41.409 | 39.97 | 1703 | -29 18053 | 0.164879 | 21.370 | 45.34 |
| SAO | - 6 3855 | 0.134636 | 55.705 | 01.70 | SAO | -29 18059 | 0.155871 | 02.777 | 06.12 |
| | - 5 3747 | 0.213768 | 26.426 | 07.59 | | -30 18892 | 0.184034 | 45.325 | 56.41 |
| | - 6 3868 | 0.122052 | 10.505 | 15.03 | | -28 17507 | 0.145740 | 26.550 | 38.46 |
| | - 6 3876 | 0.125420 | 04.913 | 45.62 | | -30 18932 | 0.185588 | 41.235 | 30.67 |
| | - 5 3756 | 0.209217 | 09.454 | 46.14 | | -29 18099 | 0.163888 | 22.332 | 25.94 |
| 1693 | - 4 5318 | 0.155250 | 12.431 | 27.71 | 1704 | -30 18763 | 0.218965 | 27.704 | 16.88 |
| SAO | - 4 5323 | 0.154569 | 32.456 | 50.18 | SAO | -30 18789 | 0.185501 | 58.561 | 59.48 |
| | - 3 5090 | 0.168760 | 32.330 | 54.44 | | -29 17963 | 0.193020 | 09.129 | 39.00 |
| | - 5 5440 | 0.159388 | 14.646 | 46.42 | | -29 17994 | 0.151851 | 49.249 | 54.81 |
| | - 3 5109 | 0.178813 | 58.602 | 29.56 | | -30 18843 | 0.130606 | 10.176 | 53.69 |
| | - 4 5362 | 0.183221 | 37.826 | 38.07 | | -30 18844 | 0.120057 | 45.623 | 50.55 |
| 1694 | - 5 5385 | 0.138103 | 37.676 | 42.06 | 1705 | - 9 5677 | 0.072827 | 30.843 | 36.44 |
| SAO | - 4 5271 | 0.172096 | 09.052 | 31.33 | SAO | - 8 5599 | 0.173806 | 07.343 | 04.20 |
| | - 4 5281 | 0.192505 | 48.969 | 36.33 | | - 8 5603 | 0.152222 | 37.079 | 47.13 |
| | - 6 5619 | 0.131313 | 56.691 | 23.06 | | - 8 5611 | 0.239216 | 14.635 | 42.83 |
| | - 4 5300 | 0.200673 | 39.561 | 27.78 | | - 9 5696 | 0.132288 | 50.328 | 47.31 |
| | - 5 5417 | 0.165310 | 42.366 | 16.17 | | - 8 5621 | 0.229642 | 21.869 | 40.98 |
| 1695 | - 5 5354 | 0.171554 | 40.172 | 43.21 | 1706 | - 7 5501 | 0.191147 | 05.138 | 23.01 |
| SAO | - 6 5567 | 0.082648 | 14.654 | 07.12 | SAO | - 6 5687 | 0.162652 | 07.859 | 28.27 |
| | - 6 5579 | 0.085486 | 01.086 | 51.94 | | - 6 5697 | 0.145593 | 57.676 | 41.63 |
| | - 4 5257 | 0.305478 | 08.299 | 25.02 | | - 5 5498 | 0.137391 | 43.621 | 10.52 |
| | - 5 5385 | 0.249509 | 37.676 | 42.06 | | - 7 5519 | 0.194232 | 20.398 | 36.76 |
| | - 6 5600 | 0.105324 | 57.906 | 56.49 | | - 6 5722 | 0.168986 | 45.348 | 59.65 |
| 1696 | - 7 5290 | 0.175365 | 57.011 | 32.56 | 1707 | - 6 5676 | 0.169625 | 49.176 | 49.48 |
| SAO | - 8 5366 | 0.167998 | 38.467 | 09.21 | SAO | - 5 5463 | 0.122771 | 56.698 | 48.75 |
| | - 7 5304 | 0.174117 | 06.375 | 39.98 | | - 5 5472 | 0.089108 | 05.509 | 59.78 |
| | - 6 5501 | 0.170132 | 49.361 | 23.55 | | - 6 5687 | 0.241808 | 07.859 | 28.27 |
| | - 8 5380 | 0.155493 | 07.813 | 11.21 | | - 6 5697 | 0.218840 | 57.676 | 41.63 |
| | - 7 5321 | 0.156896 | 41.908 | 23.66 | | - 5 5489 | 0.157849 | 36.858 | 29.30 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Stars | Depend. | R.A. | Dec. | No. | Stars | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|
| 1708 | - 5 5421 | 0.097078 | 02.079 | 04.78 | 1711 | - 4 5228 | 0.309031 | 35.466 | 36.69 |
| SAO | - 4 5315 | 0.141024 | 29.469 | 37.39 | SAO | - 4 5240 | 0.184541 | 30.391 | 28.05 |
| | - 4 5318 | 0.172634 | 12.431 | 27.71 | | - 4 5252 | 0.088496 | 44.817 | 15.08 |
| | - 6 5646 | 0.142105 | 29.944 | 03.17 | | - 3 5013 | 0.216878 | 08.371 | 35.53 |
| | - 5 5440 | 0.207634 | 14.646 | 46.42 | | - 3 5022 | 0.132052 | 30.575 | 24.64 |
| | - 4 5340 | 0.239525 | 23.645 | 32.39 | | - 4 5264 | 0.069002 | 52.645 | 30.17 |
| 1709 | - 4 5281 | 0.238701 | 48.970 | 36.33 | 1712 | - 3 4933 | 0.252726 | 32.017 | 03.19 |
| SAO | - 5 5402 | 0.186492 | 40.796 | 30.38 | SAO | - 4 5172 | 0.302642 | 16.706 | 09.11 |
| | - 5 5409 | 0.159682 | 13.207 | 17.27 | | - 2 5312 | 0.137247 | 20.199 | 59.37 |
| | - 3 5066 | 0.183763 | 37.220 | 08.37 | | - 2 5321 | 0.080120 | 03.804 | 16.29 |
| | - 4 5315 | 0.114826 | 29.469 | 37.39 | | - 4 5201 | 0.156924 | 54.734 | 30.71 |
| | - 4 5318 | 0.116537 | 12.431 | 27.71 | | - 3 4971 | 0.070341 | 44.472 | 49.29 |
| 1710 | - 4 5228 | 0.212371 | 35.466 | 36.69 | 1713 | - 3 4833 | 0.203834 | 10.464 | 55.09 |
| SAO | - 4 5240 | 0.159328 | 30.391 | 28.05 | SAO | - 5 5205 | 0.242513 | 27.026 | 57.32 |
| | - 4 5252 | 0.128502 | 44.817 | 15.08 | | - 3 4839 | 0.169424 | 29.048 | 40.39 |
| | - 3 5013 | 0.214591 | 08.371 | 35.53 | | - 3 4856 | 0.112415 | 25.432 | 28.23 |
| | - 3 5028 | 0.169016 | 33.356 | 07.21 | | - 4 5105 | 0.152378 | 07.828 | 21.81 |
| | - 4 5270 | 0.116192 | 59.872 | 31.54 | | - 4 5108 | 0.119435 | 36.345 | 42.99 |

TABLE 3

STANDARD ERRORS

| | | R.A. | Dec. |
|---|---|---|---|
| AGK3 | 4 image | $0^{s}.013 \sec \delta$ | $0''.22$ |
| SAO | 4 image | $0^{s}.021 \sec \delta$ | $0''.33$ |
| SAO | 2 image | $0^{s}.022 \sec \delta$ | $0''.36$ |

ACKNOWLEDGMENTS

I wish to thank D.S. King for his assistance.

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# Proper Motions in the Region of the Galactic Cluster NGC 5662

DAVID S. KING

ABSTRACT. Relative proper motions in the region of the galactic cluster NGC 5662 are determined with the aim of identifying stars which are non-members. The relative proper motions have an average standard error of 0".09/century and reveal 77 likely members and 111 likely non-members.

## INTRODUCTION

The open cluster NGC 5662 (R.A. = $14^h\ 31^m.6$, Dec. = $-56^o\ 20'$; 1950) has been studied photometrically by Moffat and Vogt (1973). The present investigation seeks to identify from their proper motions, those stars that are not members of the cluster.

## THE PLATES

The plates were taken with the 33cm standard astrograph (scale 1' = 1 mm) as follows:

| | Plate No. | Date Taken | Exposure | Plate Pair |
|---|---|---|---|---|
| 1 | W19 | 1892 Apr. 12 | 6 m | 1 |
| 2 | W19 | 1892 Apr. 12 | 3 m | 2 |
| 3 | 1472s | 1894 May 10 | 3 m | 3 |
| 4 | 1472s | 1894 May 10 | 1½ m | 4 |
| 5 | 2484s | 1895 June 12 | 30 m | 5 |
| 6 | 3374s | 1897 May 4 | 30 m | 6 |
| 7 | 992RH | 1902 June 6 | 80 m | 7 |
| 8 | 7797Sa | 1979 Mar. 9 | 20 m | 6 |
| 9 | 7840Sa | 1979 June 14 | 10 m | 3 |
| 10 | 7843Sa | 1979 June 25 | 15 m | 4 |
| 11 | 7853Sa | 1979 July 2 | 18 m | 1 |
| 12 | 7858Sa | 1979 July 3 | 12 m | 2 |
| 13 | 7867Sa | 1979 July 11 | 20 m | 5 |
| 14 | 7868Sa | 1979 July 16 | 20 m | 7 |

Plate pairs 1 and 2 were centred at R.A. $14^h\ 24^m$ Dec. $-56^o\ 00'$ (1900). All the other plate pairs were centred at R.A. $14^h\ 30^m$ Dec. $-57^o\ 00'$ (1900).

## MEASUREMENT

The plates were each measured in a Grubb-Parsons photoelectric measuring machine in both direct and reverse positions. The reverse positions were converted into direct measures using plate constants and the average was recorded. All stars measured were selected from the published coordinates in the Astrographic Catalogue (Sydney Observatory 1954, plate W19). The plates were measured by Mrs J. Close, Miss D. Teale, Miss J. Westaway and Mr. D. King.

## REDUCTIONS AND PROBABILITIES

The method of reduction and calculation of membership probabilities is described in a previous paper (King 1979). The distribution parameters in arc sec./century after eliminating 12 stars to obtain the best fit were:

$$\theta = -38^{\circ}.16 \quad N_f = 99 \quad X_f = -0.048 \quad \Sigma_x = 0.594$$
$$\sigma_c = 0.142 \quad N_c = 77 \quad Y_f = 0.068 \quad \Sigma_y = 0.347$$

$\theta$ is the rotation angle of the observed proper motions ($+\mu$ to $+\nu$) into a new coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions. All the other parameters are defined in this new coordinate system. $\sigma_c$ is the dispersion of the cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars. $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions.

The standard errors for individual stars have been grouped by their magnitudes, and the mean of the standard errors $\sigma_\mu$, $\sigma_\nu$ determined for different ranges are as follows:-

| Magnitude | $\sigma_\mu$ | $\sigma_\nu$ | No. of stars |
|---|---|---|---|
| | (Unit 0".01/cent) | | |
| 12.0 - 12.6 | 10.06 | 10.41 | 78 |
| 11.0 - 11.9 | 8.00 | 9.53 | 58 |
| 10.0 - 10.9 | 8.43 | 8.86 | 35 |
| 7.6 - 9.9 | 7.94 | 8.00 | 17 |
| All | 8.93 | 9.63 | 188 |

The absolute proper motion of the cluster NGC 5662 by comparison with 15 Cape Catalogue stars is -0.77 ± 0.27"/cent. in R.A. and -0.58 ± 0.29"/cent. in Dec.

The observational data follows in table 1. The various columns are:-

| | |
|---|---|
| No. | The number from the Astrographic Catalogue, Sydney Section ($14^h\ 24^m\ -56^o$ centre). |
| Mag. | The magnitude of the star taken from either the Cape Photographic Catalogue or the Sydney Astrographic Catalogue. |
| R.A. | Right ascension (1950), all prefixed by 14 hours. |
| Dec. | Declination (1950). |
| CPD No. | Cape Photographic Durchmusterung number. |
| V | Photovisual magnitude from Mermilliod. |
| M No. | Number as given in Mermilliod's Catalogue. |
| $\mu,\nu$ | Centennial proper motion in units of 0".01/cent. Motion of $\mu$ in R.A. and $\nu$ in Dec. |
| $\sigma_\mu,\sigma_\nu$ | Standard errors of centennial proper motion in units of 0".01/cent. |
| P | Probability of membership in NGC 5662. |
| Notes | 6 - Not used in calculation of distribution parameters. |

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Sydney Observatory, 1954. *Astrographic Catalogue, Sydney Section*, *19*, 26-29.

TABLE 1

THE OBSERVATIONAL DATA

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 67 | 12.4 | 35 26 | -56 56 10 | | | | - 6 | -20 | 13 | 12 | 76 | |
| 68 | 12.6 | 35 17 | -56 56 42 | | | | - 4 | - 6 | 12 | 10 | 88 | |
| 69 | 10.7 | 33 47 | -56 56 35 | -56 6356 | | | 31 | 27 | 12 | 10 | 14 | |
| 70 | 12.1 | 33 40 | -56 54 04 | -56 6354 | | | -52 | -43 | 12 | 6 | 0 | |
| 71 | 12.4 | 32 42 | -56 53 54 | | | | 25 | 3 | 6 | 11 | 68 | |
| 72 | 12.4 | 32 21 | -56 52 47 | | | | - 9 | 14 | 1 | 8 | 81 | |
| 73 | 12.6 | 32 04 | -56 52 50 | | | | -73 | -132 | 20 | 5 | 0 | |
| 74 | 12.1 | 31 24 | -56 53 51 | | | | 3 | -16 | 9 | 9 | 83 | |
| 75 | 12.6 | 31 12 | -56 53 31 | | | | -33 | -87 | 13 | 3 | 0 | |
| 76 | 12.4 | 31 10 | -56 57 30 | | | | 38 | - 6 | 9 | 5 | 28 | |
| 77 | 8.1 | 30 59 | -56 53 27 | -56 6317 | | | - 2 | 11 | 8 | 5 | 86 | |
| 78 | 11.2 | 30 54 | -56 55 49 | -56 6316 | | | -17 | -345 | 5 | 10 | 0 | 6 |
| 79 | 11.5 | 30 44 | -56 54 18 | -56 6314 | | | - 8 | -46 | 8 | 13 | 7 | |
| 81 | 12.4 | 29 55 | -56 55 13 | | | | 14 | 38 | 11 | 14 | 16 | |
| 82 | 12.1 | 29 24 | -56 57 48 | | | | 16 | 15 | 13 | 6 | 73 | |
| 83 | 12.1 | 29 01 | -56 57 33 | | | | 7 | - 2 | 12 | 15 | 88 | |
| 97 | 12.4 | 33 04 | -56 47 55 | | | | -126 | -49 | 12 | 8 | 0 | |
| 98 | 12.4 | 32 34 | -56 48 10 | | | | -38 | - 2 | 13 | 15 | 21 | |
| 99 | 12.4 | 32 01 | -56 49 21 | | | | 207 | 25 | 6 | 16 | 0 | 6 |
| 100 | 12.1 | 31 58 | -56 48 31 | | | | 7 | 20 | 10 | 7 | 74 | |
| 105 | 12.1 | 30 11 | -56 52 04 | | | | -11 | -79 | 10 | 8 | 0 | |
| 107 | 12.4 | 29 46 | -56 48 44 | | | | -130 | -99 | 15 | 11 | 0 | |
| 108 | 12.1 | 29 34 | -56 50 36 | | | | - 8 | -39 | 9 | 5 | 21 | |
| 109 | 11.5 | 29 32 | -56 49 17 | -56 6304 | | | - 1 | 0 | 8 | 10 | 89 | |
| 110 | 11.7 | 29 17 | -56 53 02 | | | | 13 | 24 | 9 | 11 | 59 | |
| 126 | 11.5 | 34 32 | -56 44 18 | -56 6360 | | | -88 | -94 | 10 | 7 | 0 | |
| 127 | 12.1 | 34 21 | -56 42 27 | | | | 1 | 21 | 3 | 8 | 74 | |
| 128 | 12.1 | 33 32 | -56 44 32 | | | | 19 | - 6 | 11 | 10 | 80 | |
| 130 | 12.4 | 32 40 | -56 44 35 | | | | 28 | 0 | 13 | 10 | 62 | |
| 132 | 12.4 | 31 48 | -56 47 24 | | | | 55 | 8 | 4 | 4 | 1 | |
| 133 | 12.1 | 31 31 | -56 43 41 | | | | 23 | -38 | 13 | 11 | 15 | |
| 134 | 10.7 | 31 28 | -56 46 45 | -56 6323 | | | -30 | 11 | 6 | 5 | 44 | |
| 135 | 11.7 | 31 19 | -56 47 00 | | | | 10 | -27 | 11 | 9 | 63 | |
| 136 | 11.6 | 31 00 | -56 45 28 | | | | -17 | -23 | 10 | 7 | 56 | |
| 137 | 11.6 | 30 55 | -56 44 38 | | | | -60 | -45 | 7 | 8 | 0 | |
| 138 | 12.1 | 29 56 | -56 44 02 | | | | -67 | -32 | 6 | 6 | 0 | |
| 139 | 11.2 | 29 54 | -56 44 15 | -56 6307 | | | - 1 | -16 | 8 | 7 | 83 | |
| 142 | 10.7 | 29 26 | -56 44 26 | -56 6302 | | | -16 | -16 | 9 | 11 | 71 | |
| 143 | 12.1 | 29 17 | -56 45 39 | | | | 31 | 31 | 13 | 9 | 9 | |
| 144 | 12.4 | 28 57 | -56 46 27 | | | | 127 | -62 | 6 | 12 | 0 | 6 |
| 145 | 12.1 | 28 56 | -56 45 43 | | | | - 4 | 29 | 5 | 9 | 54 | |
| 158 | 11.7 | 34 29 | -56 39 08 | | | | 6 | 20 | 7 | 8 | 75 | |
| 160 | 12.6 | 33 39 | -56 40 33 | | | | -475 | -417 | 10 | 24 | 0 | 6 |
| 161 | 12.4 | 33 31 | -56 42 07 | | | | -344 | -396 | 4 | 14 | 0 | 6 |
| 162 | 12.1 | 33 12 | -56 41 19 | | | | 45 | 8 | 2 | 14 | 8 | |
| 163 | 10.7 | 33 07 | -56 39 18 | -56 6347 | | | 159 | 6 | 10 | 6 | 0 | |
| 164 | 11.7 | 32 22 | -56 40 30 | | | | - 5 | -30 | 6 | 11 | 54 | |
| 165 | 10.7 | 32 10 | -56 41 21 | -56 6339 | | | 1 | -14 | 6 | 9 | 85 | |
| 166 | 12.1 | 32 08 | -56 38 02 | | | | 41 | 76 | 9 | 15 | 0 | |
| 167 | 12.4 | 31 08 | -56 38 25 | | | | -101 | -11 | 9 | 14 | 0 | |
| 168 | 9.7 | 31 03 | -56 38 37 | -56 6318 | | | 10 | - 6 | 6 | 9 | 87 | |
| 169 | 12.4 | 30 45 | -56 41 17 | | | | -23 | 6 | 14 | 14 | 68 | |
| 170 | 12.1 | 30 42 | -56 42 17 | | | | 38 | 11 | 8 | 3 | 20 | |

Table 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | μ | ν | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 171 | 11.7 | 30 06 | -56 41 13 | -56 6310 | | | -309 | -203 | 8 | 10 | 0 | 6 |
| 172 | 11.2 | 30 04 | -56 38 17 | -56 6309 | | | -164 | -11 | 7 | 10 | 0 | |
| 173 | 12.1 | 29 55 | -56 39 38 | | | | 39 | 39 | 7 | 13 | 1 | |
| 177 | 7.6 | 28 57 | -56 40 02 | -56 6296 | | | 4 | 11 | 6 | 6 | 86 | |
| 198 | 11.8 | 34 43 | -56 36 32 | -56 6362 | | | 9 | 31 | 8 | 10 | 43 | |
| 199 | 12.6 | 34 21 | -56 36 49 | | | | -36 | 46 | 14 | 13 | 1 | |
| 200 | 11.7 | 33 54 | -56 35 39 | -56 6357 | | | - 6 | -29 | 6 | 9 | 56 | |
| 201 | 10.1 | 31 51 | -56 33 17 | -56 6329 | 9.49 | 28 | 202 | -148 | 9 | 8 | 0 | 6 |
| 202 | 9.4 | 31 40 | -56 33 09 | -56 6326 | 9.42 | 29 | 7 | - 9 | 5 | 11 | 87 | |
| 203 | 10.2 | 31 25 | -56 35 04 | -56 6322 | 8.59 | 30 | 42 | 46 | 11 | 3 | 0 | |
| 204 | 10.2 | 31 03 | -56 36 24 | -56 6319 | | | 4 | - 2 | 3 | 5 | 89 | |
| 205 | 11.2 | 30 40 | -56 33 07 | | | | -18 | 0 | 8 | 5 | 79 | |
| 206 | 10.7 | 30 11 | -56 37 56 | -56 6311 | | | 4 | 12 | 8 | 10 | 85 | |
| 207 | 12.1 | 29 41 | -56 35 26 | | | | 4 | - 8 | 10 | 14 | 88 | |
| 208 | 10.4 | 29 37 | -56 36 19 | -56 6305 | | | - 7 | - 2 | 8 | 2 | 88 | |
| 209 | 12.1 | 29 02 | -56 36 24 | | | | 17 | 100 | 4 | 3 | 0 | |
| 236 | 12.4 | 35 07 | -56 27 38 | | | | -96 | -116 | 14 | 9 | 0 | |
| 240 | 10.7 | 33 12 | -56 30 18 | -56 6349 | | | 41 | 46 | 7 | 9 | 0 | |
| 241 | 12.4 | 33 03 | -56 31 14 | | | | 60 | 30 | 11 | 23 | 0 | |
| 242 | 12.1 | 32 51 | -56 29 30 | | | | 70 | -35 | 6 | 14 | 0 | |
| 243 | 11.2 | 32 16 | -56 30 46 | -56 6342 | | | -62 | 66 | 8 | 8 | 0 | |
| 244 | 11.7 | 32 05 | -56 31 52 | | | | 12 | 35 | 7 | 12 | 26 | |
| 245 | 10.4 | 32 05 | -56 32 14 | -56 6336 | | | - 6 | 13 | 9 | 6 | 83 | |
| 246 | 9.9 | 31 57 | -56 29 58 | -56 6335 | 9.80 | 26 | -10 | -10 | 8 | 6 | 84 | |
| 247 | 12.1 | 31 57 | -56 31 41 | | | | -70 | -78 | 13 | 7 | 0 | |
| 248 | 11.7 | 31 40 | -56 29 43 | | | | 9 | - 1 | 11 | 9 | 88 | |
| 249 | 11.7 | 31 38 | -56 30 36 | | | | 1 | - 4 | 9 | 13 | 89 | |
| 250 | 9.6 | 31 33 | -56 30 11 | -56 6324 | 9.36 | 27 | - 2 | - 4 | 10 | 4 | 89 | |
| 251 | 9.9 | 31 15 | -56 28 33 | -56 6321 | | | 35 | 36 | 9 | 9 | 2 | |
| 252 | 10.7 | 31 12 | -56 29 34 | -56 6320 | | | -15 | 6 | 6 | 9 | 81 | |
| 253 | 12.1 | 31 09 | -56 31 59 | | | | -22 | -21 | 16 | 5 | 48 | |
| 254 | 10.4 | 30 51 | -56 29 42 | -56 6315 | | | 8 | - 7 | 4 | 6 | 87 | |
| 256 | 12.1 | 30 47 | -56 32 17 | | | | -43 | 19 | 12 | 4 | 5 | |
| 257 | 10.4 | 30 40 | -56 31 34 | -56 6313 | | | 8 | - 5 | 11 | 8 | 88 | |
| 259 | 9.9 | 30 16 | -56 31 34 | -56 6312 | | | - 7 | 0 | 10 | 9 | 88 | |
| 262 | 10.7 | 28 50 | -56 28 46 | | | | -37 | 38 | 13 | 10 | 2 | |
| 281 | 11.5 | 34 33 | -56 26 26 | -56 6361 | | | -11 | - 6 | 12 | 10 | 85 | |
| 282 | 12.4 | 33 59 | -56 25 36 | | | | -37 | -19 | 12 | 14 | 12 | |
| 283 | 12.6 | 33 32 | -56 24 20 | | | | 20 | 38 | 11 | 5 | 10 | |
| 284 | 11.2 | 33 17 | -56 25 55 | -56 6351 | | | 60 | 79 | 6 | 8 | 0 | |
| 285 | 11.7 | 33 10 | -56 23 24 | -56 6348 | | | 10 | -18 | 9 | 12 | 79 | |
| 287 | 11.7 | 32 37 | -56 27 29 | | | | 36 | 42 | 10 | 10 | 1 | |
| 288 | 12.1 | 32 34 | -56 24 26 | | | | -12 | -25 | 9 | 13 | 60 | |
| 291 | 11.2 | 32 22 | -56 24 54 | -56 6344 | 11.33 | 25 | 6 | - 4 | 6 | 7 | 88 | |
| 292 | 8.2 | 32 11 | -56 24 01 | -56 6340 | 8.29 | 1 | - 3 | 8 | 8 | 8 | 87 | |
| 293 | 10.2 | 32 06 | -56 23 38 | -56 6337 | 10.65 | 2 | - 5 | -25 | 7 | 11 | 68 | |
| 294 | 11.5 | 32 03 | -56 24 52 | | 11.68 | 24 | - 2 | - 6 | 9 | 12 | 88 | |
| 295 | 9.9 | 31 55 | -56 23 51 | -56 6333 | 9.86 | 4 | 4 | -19 | 5 | 7 | 80 | |
| 296 | 11.5 | 31 55 | -56 24 26 | -56 6332 | 11.56 | 22 | 5 | 2 | 7 | 8 | 89 | |
| 297 | 10.4 | 31 51 | -56 23 35 | -56 6330 | 10.60 | 6 | 28 | 38 | 4 | 7 | 4 | |
| 298 | 9.2 | 31 50 | -56 24 11 | -56 6328 | 9.14 | 5 | - 2 | - 5 | 10 | 10 | 89 | |
| 299 | 11.5 | 31 43 | -56 24 48 | | 11.40 | 23 | 14 | 28 | 3 | 8 | 46 | |
| 300 | 11.7 | 31 12 | -56 27 52 | | | | - 1 | - 4 | 7 | 9 | 89 | |
| 301 | 11.7 | 30 56 | -56 23 48 | | | | -14 | - 9 | 4 | 6 | 81 | |
| 303 | 12.1 | 30 07 | -56 24 46 | | | | 24 | 14 | 6 | 11 | 59 | |
| 304 | 10.1 | 30 03 | -56 24 06 | -56 6308 | | | 3 | 9 | 5 | 7 | 87 | |
| 305 | 11.2 | 29 45 | -56 27 17 | -56 6306 | | | - 3 | - 4 | 7 | 9 | 89 | |
| 306 | 11.7 | 29 34 | -56 24 00 | | | | - 1 | 74 | 4 | 12 | 0 | |
| 307 | 11.2 | 28 58 | -56 27 01 | -56 6298 | | | - 6 | - 7 | 3 | 8 | 87 | |
| 308 | 11.7 | 28 48 | -56 26 47 | | | | - 3 | 54 | 10 | 12 | 1 | |
| 320 | 11.7 | 34 35 | -56 18 35 | -55 6087 | | | 4 | -22 | 10 | 10 | 76 | |
| 321 | 12.1 | 34 22 | -56 20 53 | | | | 16 | -20 | 12 | 14 | 71 | |
| 322 | 12.1 | 34 04 | -56 20 12 | | | | 35 | 19 | 13 | 2 | 18 | |
| 324 | 12.4 | 33 30 | -56 18 42 | | | | -60 | 2 | 5 | 16 | 0 | |
| 325 | 11.5 | 33 26 | -56 20 04 | -56 6353 | | | - 1 | 18 | 9 | 9 | 79 | |
| 326 | 12.4 | 33 25 | -56 19 48 | | | | -33 | -72 | 19 | 1 | 0 | |
| 327 | 12.4 | 33 16 | -56 22 28 | | | | -275 | -166 | 8 | 10 | 0 | 6 |

Table 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 328 | 10.7 | 32 52 | -56 19 28 | -55 6073 | 11.01 | 15 | - 1 | 0 | 10 | 9 | 89 | |
| 329 | 11.2 | 32 47 | -56 21 52 | -56 6346 | 11.05 | 16 | - 6 | - 2 | 8 | 9 | 88 | |
| 331 | 11.2 | 32 42 | -56 17 52 | -55 6072 | 11.29 | 17 | -149 | -30 | 6 | 11 | 0 | |
| 332 | 10.2 | 32 39 | -56 19 47 | -55 6071 | 10.56 | 14 | 38 | 41 | 6 | 7 | 1 | |
| 333 | 11.7 | 32 25 | -56 20 35 | | 11.55 | 18 | 80 | 7 | 9 | 12 | 0 | |
| 334 | 8.7 | 32 25 | -56 18 00 | -55 6067 | 8.82 | 11 | - 3 | - 6 | 8 | 7 | 88 | |
| 336 | 10.7 | 32 23 | -56 19 38 | -55 6066 | 11.12 | 12 | - 9 | -16 | 7 | 11 | 79 | |
| 337 | 10.4 | 32 13 | -56 20 18 | -56 6341 | 10.78 | 13 | - 7 | -10 | 7 | 11 | 85 | |
| 338 | 12.1 | 32 12 | -56 21 21 | | | | -16 | -21 | 16 | 11 | 62 | |
| 339 | 11.7 | 32 12 | -56 18 11 | | 11.88 | 19 | -14 | 31 | 6 | 10 | 38 | |
| 340 | 12.1 | 32 04 | -56 22 49 | | 10.67 | 3 | -81 | -49 | 12 | 12 | 0 | |
| 341 | 10.1 | 31 56 | -56 20 50 | -56 6334 | 9.88 | 7 | 5 | -29 | 8 | 11 | 60 | |
| 342 | 8.9 | 31 32 | -56 20 39 | -56 6325 | 7.06 | 8 | 4 | 14 | 7 | 10 | 83 | |
| 343 | 10.2 | 31 29 | -56 18 31 | -55 6061 | 10.72 | 21 | - 2 | - 2 | 6 | 4 | 89 | |
| 344 | 12.1 | 31 15 | -56 20 07 | | | | - 4 | -15 | 6 | 6 | 83 | |
| 345 | 11.7 | 30 57 | -56 21 21 | | | | 43 | 50 | 13 | 13 | 0 | |
| 346 | 12.4 | 30 56 | -56 20 26 | | | | 33 | 37 | 10 | 6 | 3 | |
| 347 | 12.1 | 30 55 | -56 20 47 | | | | 1 | 32 | 7 | 10 | 44 | |
| 352 | 12.2 | 30 05 | -56 22 28 | | | | - 9 | -11 | 13 | 11 | 84 | |
| 355 | 11.2 | 29 42 | -56 21 57 | | | | -22 | 53 | 10 | 13 | 1 | |
| 356 | 12.1 | 29 37 | -56 20 12 | | | | -63 | 27 | 12 | 9 | 0 | |
| 357 | 10.1 | 29 19 | -56 19 17 | -55 6039 | | | -90 | -30 | 10 | 10 | 0 | |
| 358 | 11.7 | 29 12 | -56 20 31 | | | | 56 | 29 | 9 | 6 | 0 | |
| 359 | 10.7 | 29 11 | -56 20 47 | -56 6300 | | | 4 | 28 | 7 | 11 | 56 | |
| 360 | 12.1 | 29 04 | -56 18 37 | | | | -231 | -40 | 10 | 22 | 0 | 6 |
| 377A | 8.4 | 35 27 | -56 16 57 | -55 6092 | | | 118 | 186 | 14 | 21 | 0 | 6 |
| 377 | 12.1 | 34 38 | -56 12 54 | | | | 34 | 10 | 16 | 16 | 34 | |
| 379 | 11.2 | 34 17 | -56 15 05 | -55 6084 | | | -55 | 20 | 8 | 14 | 0 | |
| 381 | 10.7 | 33 44 | -56 12 46 | -55 6078 | | | -30 | -28 | 10 | 10 | 14 | |
| 382 | 10.7 | 33 17 | -56 13 38 | -55 6075 | | | 8 | 25 | 11 | 12 | 62 | |
| 383 | 12.1 | 32 48 | -56 14 49 | | | | - 5 | 25 | 5 | 11 | 65 | |
| 384 | 12.1 | 32 44 | -56 14 30 | | | | - 3 | -62 | 7 | 10 | 0 | |
| 385 | 11.7 | 32 31 | -56 16 01 | | | | -41 | -45 | 7 | 9 | 0 | |
| 387 | 9.1 | 32 25 | -56 14 32 | -55 6068 | 9.19 | 10 | - 4 | - 2 | 5 | 7 | 89 | |
| 388 | 9.3 | 31 55 | -56 15 17 | -55 6064 | 9.37 | 9 | 4 | -10 | 9 | 6 | 87 | |
| 389 | 11.5 | 31 51 | -56 14 19 | -55 6063 | 11.56 | 20 | - 1 | -13 | 4 | 9 | 86 | |
| 391 | 11.2 | 31 11 | -56 17 38 | -55 6057 | | | 35 | 30 | 10 | 7 | 6 | |
| 392 | 12.1 | 30 36 | -56 15 58 | | | | 2 | 68 | 4 | 11 | 0 | |
| 393 | 11.7 | 30 36 | -56 15 11 | | | | 10 | -10 | 7 | 8 | 86 | |
| 394 | 11.7 | 30 13 | -56 17 34 | | | | -35 | -20 | 6 | 14 | 15 | |
| 396 | 10.7 | 29 28 | -56 15 31 | -55 6042 | | | -128 | -254 | 11 | 10 | 0 | 6 |
| 397 | 12.1 | 29 25 | -56 13 58 | | | | -31 | 44 | 5 | 14 | 2 | |
| 398 | 12.1 | 29 07 | -56 16 54 | | | | - 7 | 20 | 27 | 16 | 74 | |
| 399 | 11.5 | 29 05 | -56 14 45 | | | | 0 | 58 | 13 | 16 | 0 | |
| 411 | 10.8 | 35 02 | -56 08 04 | -55 6089 | | | -28 | 28 | 8 | 14 | 20 | |
| 412 | 12.4 | 32 18 | -56 08 21 | | | | -33 | 24 | 11 | 16 | 17 | |
| 413 | 11.7 | 32 10 | -56 11 19 | | | | 64 | 52 | 6 | 9 | 0 | |
| 414 | 12.1 | 32 04 | -56 09 40 | | | | -359 | -367 | 12 | 3 | 0 | 6 |
| 417 | 11.7 | 31 41 | -56 10 43 | -55 6062 | | | -10 | -18 | 5 | 11 | 76 | |
| 419 | 10.4 | 31 17 | -56 12 47 | -55 6058 | | | 10 | -22 | 10 | 9 | 74 | |
| 420 | 12.1 | 31 06 | -56 09 34 | | | | 17 | - 2 | 3 | 13 | 82 | |
| 421 | 12.1 | 31 00 | -56 10 51 | | | | 22 | 18 | 10 | 1 | 56 | |
| 424 | 12.1 | 30 24 | -56 10 49 | | | | -16 | - 9 | 2 | 16 | 78 | |
| 426 | 11.5 | 29 24 | -56 08 51 | -55 6040 | | | - 9 | -16 | 8 | 10 | 79 | |
| 427 | 12.4 | 29 12 | -56 10 52 | | | | 14 | 14 | 1 | 4 | 77 | |
| 449 | 12.5 | 34 32 | -56 02 37 | | | | -41 | 4 | 17 | 26 | 14 | |
| 450 | 12.4 | 34 29 | -56 06 17 | | | | 16 | -40 | 16 | 11 | 18 | |
| 455 | 11.7 | 32 45 | -56 05 16 | | | | -26 | -85 | 9 | 2 | 0 | |
| 456 | 11.7 | 32 14 | -56 07 13 | | | | -26 | 62 | 9 | 9 | 0 | |
| 457 | 11.7 | 31 53 | -56 06 54 | | | | 7 | -40 | 10 | 15 | 23 | |
| 458 | 12.0 | 30 28 | -56 05 17 | | | | 22 | - 8 | 13 | 7 | 74 | |
| 483 | 10.7 | 34 21 | -56 02 02 | -55 6085 | | | -23 | - 7 | 11 | 11 | 67 | |
| 485 | 11.7 | 32 06 | -56 00 01 | | | | 69 | 47 | 14 | 5 | 0 | |
| 486 | 11.7 | 31 57 | -56 02 02 | | | | 22 | 36 | 10 | 4 | 12 | |
| 487 | 10.1 | 31 20 | -56 02 40 | -55 6060 | | | 25 | -11 | 12 | 16 | 66 | |
| 489 | 12.1 | 31 04 | -56 00 37 | | | | -39 | - 9 | 12 | 8 | 15 | |

Table 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\mu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 491 | 10.7 | 30 20 | -55 59 35 | -55 6050 | | | -11 | 45 | 13 | 12 | 7 | |
| 494 | 9.1 | 29 44 | -55 59 46 | -55 6046 | | | 9 | -24 | 7 | 1 | 70 | |

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# Some Spacecraft I Have Known*

K. G. McCracken

## INTRODUCTION

Spacecraft have personalities of their own. Some are attractive to look at; others look like an unsuccessful piece of cubist sculpture. Some are very demanding on the experimenter, while others are very easy to get on with. The great majority of them, I am pleased to say, work exceedingly well, and for a long time. It is a commonly observed phenomenon that equipment is much more reliable in space than in the laboratory. People seem to have a bad effect on space equipment.

Space research is carried out from satellites, rockets and from earth. In the following, I briefly touch on my experiences with each method. I also touch on that important problem "what do you do when your scientific interest seems to have dried up?". The short answer is "be thankful, a change is good for you".

## THE CRUSADES OF SIR LAUNCH-A-LOT

My first direct involvement with satellites commenced in 1962, when NASA announced a series of spacecraft to be flown during the forthcoming International Quiet Sun Year (IQSY). The primary goals of the missions were the measurement of the "baseline" properties of the interplanetary medium while the sun was very inactive. There was to be open competition for the space available on the spacecraft.

By today's standards, the spacecraft were minute. A grand total of 7 kilograms was available for all experiments; 5 watts of power; and typical data transmission rates of ]6 bits per second (i.e. about 4 decimal digits per second). The spacecraft was to be "magnetically clean" and an absolute minimum of ferromagnetic materials was to be used in its construction. The fact that transistors, photomultipliers and many electronic devices use large quantities of a magnetic alloy was mercifully unknown to us at the time. We soon learned; the hard way.

My group proposed an experiment to measure the anisotropic characteristics of the "galactic" cosmic radiation that enters the solar system from elsewhere in the galaxy. The measurement was designed to yield the average properties of the interplanetary magnetic field in the solar system, and was therefore complementary to the direct measurements of the magnetic field and solar plasma (the "solar wind") that were to be made at the spacecraft. To our unending surprise, we were one of the six experiments chosen for the flights.

* *Paper invited by Council.*

We realized that we had serious problems soon after we commenced the detailed design of the experiment. We had been given a weight allowance of 2.05 kilograms, while the smallest cosmic-ray detector we could build would weigh 1.60 kilograms leaving only 450 grams for electronics, power supplies, etc. It seemed quite impossible.

And then, as happens so often in science, a little luck came our way. Three kilometres away from my laboratory was the then relatively small company, Texas Instruments. I recruited one of their employees as my electronic engineer. And he said "why not use integrated circuits?". The first commercial production of ICs was still six months in the future, and none of my group had ever heard of such things. However, we obtained samples from the pilot production run (through the old boy network) and found they would do everything we wanted, with weight to spare!

Finding you can do it is one thing; being allowed to do it on a spacecraft is an entirely different matter. Reliability is of paramount importance, and proof of reliability is expensive. After an immense amount of paper work, argument and some vitriol, we were authorized to become the first experimenters to use ICs in an interplanetary spacecraft.

Pioneer VI was launched in December 1965. Within days our detector was telling us, in no uncertain terms, that the sun was far from quiet (Fig. 1). For more than 70% of the time, the galactic cosmic radiation was totally obscured by solar cosmic rays. Luck was with us again; the solar cosmic rays proved to be by far the more interesting of the two. We published eight papers on the solar cosmic-ray phenomena, versus a single rather lightweight one concerning the galactic radiation. It is interesting to ponder, however, that we would have been very unlikely to have been selected for the flight if we had proposed a solar cosmic-ray experiment.

Over the subsequent three years we built and flew experiments on six more spacecraft. While Pioneer VI was limited to measuring protons in the range 7.5-90 MeV, later experiments extended the proton range to include 1-8 MeV, and also measured relativistic electrons (i.e. E > 500 keV). In the later spacecraft the fluxes were measured from eight different directions, as against four directions in Pioneer VI. Each improvement was a response to the desire to look at the physics of the interplanetary region at different scales. For example, measurements of the 100,10 and 1 MeV proton fluxes indicated the degree of "roughness" of the interplanetary magnetic field over distances

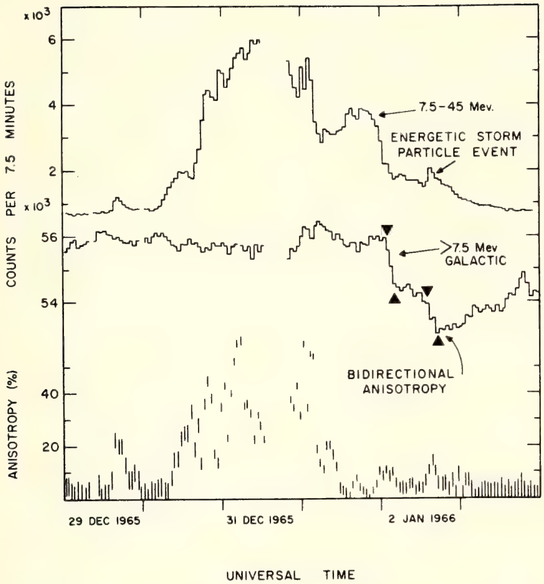


Fig. 1. The upper graph shows the arrival of low-energy cosmic rays from a solar flare that occurred early on 30 December 1965. The flux of non-solar cosmic rays remained essentially constant until 2 January 1966, when the magnetohydrodynamic shock wave generated by the flare reached the spacecraft. (From McCracken *et al.*, 1967)

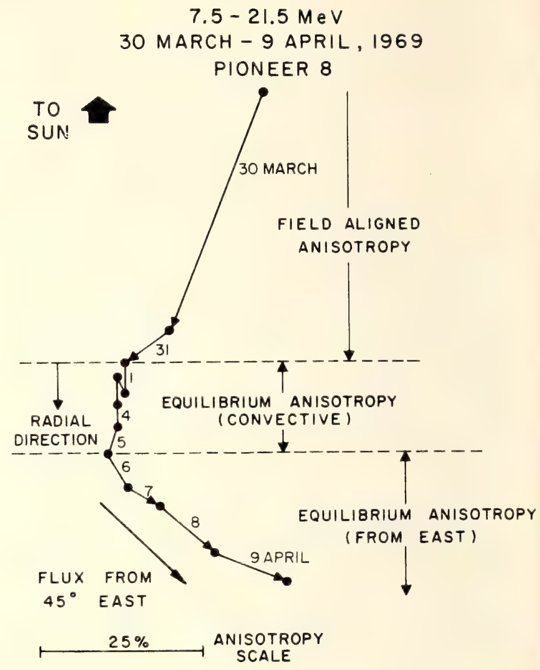


Fig. 2. Summarizing the behaviour of the cosmic-ray flow vector as a function of time, subsequent to a solar flare on 30 March 1969. (From McCracken *et al.*, 1971)

of the order of 1.9 x $10^{-3}$, 6 x $10^{-4}$ and 6.4 x $10^{-6}$ astronomical unit (AU; the distance from the sun to the earth).

Five years, seven spacecraft and over a hundred solar flares gave us an entirely new understanding of the manner in which cosmic rays flow under the influence of the interplanetary magnetic field. This understanding is illustrated by Figure 2. The first cosmic rays reach the satellite by travelling along the lines of force of the solar system field (Fig. 3). This is understandable through simple orbit theory applied to a charged particle in a well-behaved magnetic field.

By the end of the first day, however, the maximum flux of cosmic rays is no longer parallel to the interplanetary magnetic vector. It is parallel to the direction of flow of the solar wind. The solar cosmic rays have been scattered by small kinks in the interplanetary field and move, en masse, as if attached to the moving solar wind. They are "surf-riding" out of the solar system with the radially expanding solar wind.

After several more days, the maximum flux of solar radiation is from a direction at right angles to the interplanetary magnetic field, By now, most of the cosmic rays generated in the original solar flare have ridden the wind to

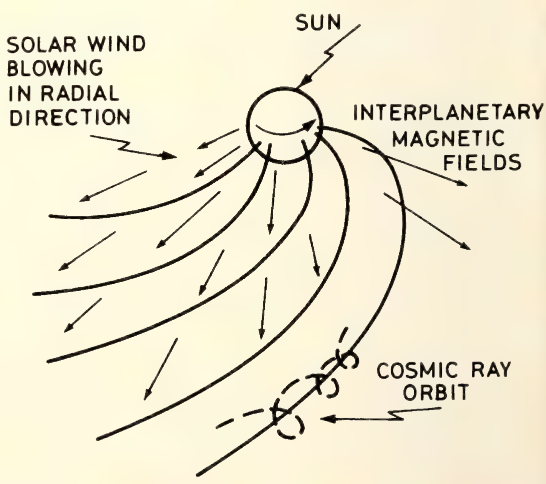


Fig. 3. Summarizing the nature of the interplanetary magnetic field, and the manner in which a low-energy cosmic ray travels from the sun to the spacecraft by spiralling along the surface of a magnetic tube of force. (From McCracken, 1969)

points well outside the orbit of earth. Some of these particles are scattered into orbits that cause them to spiral back along the interplanetary lines of force towards the sun. It can be shown that this implies that the flux will be a maximum at right angles to the magnetic induction vector. It all seems simple and quite straightforward now, but the sun had to give us many hints before we, and our theoretical colleagues, could tell us how obvious it all is.

## NEW FIELDS

While we were preparing Pioneer VI for the Quiet Sun Year, a new field of astronomy was being born. My former boss at the Massachusetts Institute of Technology, Bruno Rossi, confounded the theoreticians when he and his colleagues observed X-rays coming from near the centre of the galaxy. A repeat performance of the radio astronomy story seemed an exciting possibility.

Rossi's pioneering discovery was made by detecting 2-8 keV X-rays. These are rapidly absorbed in the atmosphere, and must therefore be measured either from a rocket or a satellite. However, the absorption length of X-rays rapidly increases with energy, and simple calculations showed that 30 keV X-rays might be observable using an instrument carried to about 40 000 metres on a high-altitude balloon.

At the time (1963), we were preparing to fly a balloon version of our Pioneer experiment from Hyderabad, India, as a contribution to the International Quiet Sun Year. We therefore decided, on very short notice, to include an X-ray astronomy "hitchhiker" in our balloon experiment. Despite its extreme simplicity, it detected a strong X-ray source in the constellation Cygnus. It showed that X-ray spectra extended to high energies, making the mechanism of origin seem even more remarkable.

At this time I was preparing to return to Australia in 1966, and was actively seeking a research activity that could be carried out at home. The Woomera rocket range; the balloon-launching base at Mildura; the galactic centre being in the southern sky; and the success in India made X-ray astronomy the obvious choice.

The first problem was to gain access to rocket flights from Woomera. While over 200 "Skylark" rockets had been flown as part of the 50-50 British-Australian joint project, no Australian experiment had ever been accepted for flight. Therefore, together with Geoff Fenton of the University of Tasmania, I approached the British authority responsible for the scientific programme at Woomera. At that time Australians still had "British" passports and in jest we pointed this out, saying we wanted to apply to fly as British, not Australians. The British thought it was a huge joke, and we were accepted. And so it was that the first Australian experiment flew out of Woomera on the 244th Skylark launched as part of the joint programme.

Lady luck was particularly kind to us this time. Predictably, we discovered several new X-ray sources (Fig. 4) because we could see the 40% of

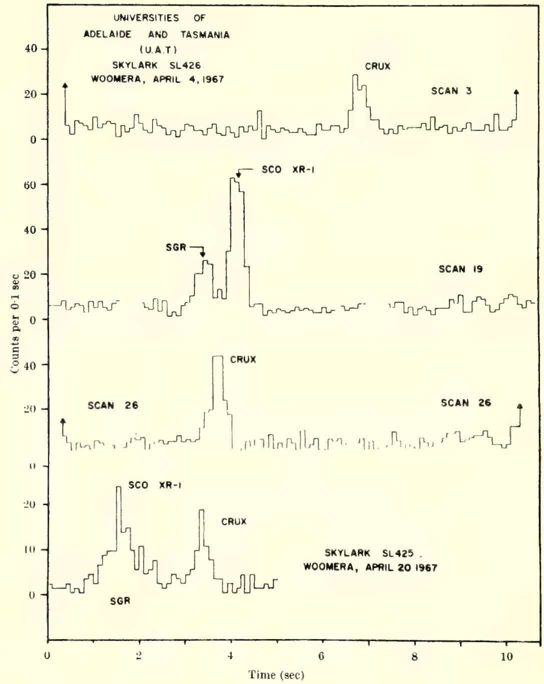


Fig. 4. Portion of the data obtained by our first X-ray astronomy flight. The Sagittarius and Scorpio sources had been observed from the northern hemisphere. The Crux source was at a Declination of -60°, and could only be seen from the southern hemisphere. (From Harries *et al.*, 1967)

the celestial sphere that is invisible from the northern hemisphere. Our two flights also provided a much more important result, however, The intensity of one of the new sources in the southern sky decreased substantially in the period between the flights. Six weeks later it was invisible. We had positive proof that X-ray stars vary in intensity. This set distinct limits on the nature of X-ray stars. It paved the way for the postulation of such exotic source mechanisms as gravitational accretion of mass onto white dwarfs and, later, black holes.

## DOWN TO EARTH

By the end of the 1960s, the prospects for conducting significant space research in Australia were very dim indeed. The Skylark programme was being discontinued from Woomera. In the USA, space research was increasingly "experiment by committee". I decided it was time to change my research interests again.

I therefore sought an area of research that was closely aligned to the industrial and political aspirations of Australia. The history of astronomy in the 18th century; chemistry in 19th-century Germany; and space research in the USSR and USA indicated the wisdom of such an alignment.

At the time, the nickel boom was suffering its terminal series of convulsions. It had become clear that the exploration technology developed for recently glaciated countries (e.g. Canada and Sweden) had failed miserably in regions of old, thick, saline soils. Development of a technology tailored to the Australian environment was clearly necessary. The Commonwealth Scientific and Industrial Research Organization (CSIRO) decided to enter this area of research, and I was lucky to be offered a job with them. This required supreme courage on their part; I knew absolutely nothing about minerals exploration.

The subsequent decade has emphasized the virtue of a scientist changing his research interests several times during his professional life. Being unencumbered by the dead hand of convention, and possessing several very unconventional skills, my colleagues have made a number of significant advances in response to the challenge presented by the Australian environment. In particular, the technology and mental attitudes of space research have proven to be important tools in meeting this challenge. The only real problem has been the very human one of communication; without a common background, serious misunderstanding can occur between the practitioner and the researcher. But that is another story!

To illustrate the application of a "space research" mentality to minerals exploration, I cite a single example of recent work that is now of major practical importance in Australia, and which is providing Australia with a significant international reputation.

In the late 1960s, NASA, in collaboration with the US Geological Survey, began building a satellite to provide "photographs" of the earth which could aid the management of resources. These satellites became known as the Landsat series. A group of Australian scientists proposed a series of experiments involving Landsat, which were accepted by NASA.

The subsequent history of Landsat in Australia is extremely illuminating. It demonstrates, yet again, the danger inherent in uncritical transfer of technology from one country to another.

The Landsat images available in 1972-73 were found to offer very little that Australia didn't know already. The imported technology had been tried, and had been found wanting. Industry, and the research community, rapidly lost interest in the product.

Then Andy Green in my laboratory made an extremely important discovery. He showed that much of the detail being transmitted by the spacecraft was never reaching the Australian user. The processing and copying procedures that were right for many parts of the world were wrong for Australia. From space, Australia is a very bright continent, and inadequate allowance was being made for this. The resulting images of Australia were noisy and of low contrast.

Green therefore went back to the digital data that were originally transmitted by the spacecraft. He and his co-workers developed computer techniques that yielded a greatly improved Landsat product. But was the improved product of any practical use?

In the first place, it was clear that Landsat's role would be to augment existing data sources, and that the satellite data would probably assist in some applications, but not in others. It was also clear that some of Landsat's advantages would be in areas involving commercial secrecy, such as crop prediction and mineral exploration. Preliminary investigations made it clear that it would be virtually impossible to gain access to the data of most interest to us in this regard. Further, our resources were inadequate for investigating enough separate applications to reach a statistically significant result.

We solved this problem of assessing the product by involving Australian industry in the research. Through the Australian Mineral Industries Research Association, we set up eight "characteristic regions" in which to conduct our joint investigations. The nine companies involved contributed their own large-scale geological maps, etc., and provided assistance during data collection on the ground.

In addition, however, we knew the companies would then use the technology they were gaining in the project on exploration prospects that were too sensitive for discussion with us. We knew that their success in these preliminary investigations would determine whether their Boards would endorse routine use of the technology in the future. These would be the real tests of practical usefulness of the new techniques.

Our joint experiment with industry has now been running for three years. We have all the conventional results of such scientific work: numerous papers; demand to speak overseas; many international visitors. These tell us nothing about the original question, "how useful is Landsat?". No one is about to tell us if Landsat helped them find a new orebody; or how much time and money it saved. But we can observe certain phenomena. Thus quite a few mining companies are now setting up equipment similar to ours, which will give them greater accessibility to the Landsat data as well as improved confidentiality. Each installation costs no less than $100,000. Sales of our computer-enhanced imagery have increased fourfold each year since 1977, and are now estimated to run in excess of $300,000 p.a. Many companies now have "Landsat specialists", and job advertisements specify "experience with Landsat". We conclude with confidence that the mining industry finds Landsat to be very useful indeed.

## CONCLUSION

It has been a marvellous experience to participate in the "space research" era from the very beginning. A whole host of new discoveries have been made, and it has been immensely stimulating to contribute to the radical changes in scientific knowledge that have ensued. Luck, hard work, a little guile, a willingness to gamble and an open

mind seem to be the main ingredients that have led to success. I suspect it is so in all fields of science.

After ten heady years, it has been an invigorating experience to apply myself to the problems concerned with the Australian part of spaceship earth. I have found "space" skills to be highly relevant. I venture to say that two of our most successful projects would not have succeeded without our knowledge of space skills. The sales that have resulted from these projects amount to in excess of $750,000 p.a. already; the total benefit to the Australian economy exceeds this by a factor of 10.

It is well to recall that many Australians regard space research as a "waste of the American taxpayers' money". They are probably totally unaware of the role space research has played in providing Australia with an excellent international telephone service, more accurate weather predictions, and improved exploration for minerals (to name three). I see space research as a further example of the symbiotic relationship between the pursuit of knowledge and the derivation of practical benefits. To pursue one of these and ignore the other will be to the long-term disadvantage of all mankind, since it will kill both the intellectual, and the practical outworkings of science.

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# Study of the Effect of Chloramphenicol on Photochemical Formation of Self-Sustaining Coacervates in Presence of Low Concentration of Biological Minerals

K. Bahadur, S. Ranganayaki, S. Kumar and A. Krishna

ABSTRACT. The number of self-sustaining particles formed in sterilised aqueous mixture, containing ammonium molybdate, diammonium hydrogen phosphate and formaldehyde in presence of small concentration of biological minerals, increase on exposure to sunlight, if a small concentration of chloramphenicol is added in the mixture. On prolonged exposure, the number of particles does not increase in the mixture which has high concentration of chloramphenicol and the inhibition in the formation of particles is proportional to the concentration of chloramphenicol in the irradiated mixture.

Thorough investigations of the origin of life have been undertaken during the last two decades based upon the theories of chemical evolution suggested by Oparin (1) and Haldane (2). The underlying idea is that the first molecule which formed the earliest living systems came about by a process of molecular evolution to form the earliest living system. A lot of data has been collected during this period to suggest the natural processes under which the biochemicals forming the earliest living cells are synthesised. Reviews on abiogenesis have appeared (3,4).

Another important step in the investigation of the processes of "life synthesis" is the organisation of specific molecular associations, which show the properties of biological order. In this field the work on microspheres by Fox (5) and coacervates by Oparin (6), concerns the structures which could be synthesised under natural specific conditions.

The work on 'Jeewanu' reported in 1963 by Bahadur et. al. (7,8,9,10) describes the formation of microstructures from sterilised aqueous mixtures of formaldehyde, ammoniacal nitrogen and biological minerals, on exposure to light. The presence of various biochemicals in these mixtures have been reported (3,11). These particles have a boundary wall and distinct internal structures. The particles consist of a number of amino acids in free and combined form, nucleic acid bases such as adenine, guanine, cytosine, uracil and thymine, sugars such as ribose, deoxyribose glucose, fructose, a number of organic acids and material with enzyme-like activity. The work has been confirmed in a number of laboratories (11,12).

In 1970 Bahadur and Ranganayaki synthesised self-sustaining coacervates by exposing sterilized aqueous mixtures containing ammonium molybdate, diammonium hydrogen phosphate, biological minerals consisting of sodium chloride, potassium sulphate, magnesium sulphate, calcium acetate and potassium dihydrogen phosphate and formaldehyde to sunlight or artificial light (13). These particles have a boundary wall and internal structures and a number of biochemicals as amino acid in free and combined state, sugars, nucleic acid bases and enzyme-like materials. They "grow" from within, multiply by budding and have metabolic activities. The boundary wall is composed of phospholipids (14). The particles have been fixed with biological fixatives and stained with a number of biological dyes (15).

As these particles appeared to show a number of life-like properties, it was of interest to observe the effect of an antibiotic, viz. chloramphenicol when mixed before exposure to radiation, on the formation of these microstructures. It has already been shown that these particles are antibiotic sensitive (16). Tetracycline inhibits the formation of these particles (17). Although a high concentration of antibiotic in the irradiated mixture inhibits the formation of particles, smaller concentrations act as activators.

## EXPERIMENTAL

Aqueous solutions of ammonium molybdate 4% (W/V) and diammonium hydrogen phosphate 3% (W/V) were prepared. The mineral solution was made up by dissolving 20 mg each of sodium chloride, potassium sulphate, magnesium sulphate, calcium acetate and potassium dihydrogen phosphate in 100 ml distilled water. 2 ml of 36% formaldehyde solution was used in each mixture. Chloramphenicol solution was prepared by dissolving 50 mg of chloramphenicol in 5 ml distilled water.

Into each of six test tubes, 2 ml of ammonium molybdate solution, 4 ml of diammonium hydrogen phosphate solution and 2 ml mineral solution were added. The tubes were cotton wool plugged and sterilised in an autoclave at 15 lb pressure for 30 minutes. The test tubes were cooled to room temperature and then 0.2 ml, 0.4 ml, 0.6 ml, 0.8 ml and 1.0 ml of chloramphenicol solution were added to five of the test tubes. The sixth one was left as a control. The total volume of each mixture was made up to 9.0 ml by adding sterilized distilled water aseptically followed by 2 ml of formaldehyde solution. The test tubes were shaken gently and the mixtures were then exposed to sunlight.

The mixtures became blue when exposed to sunlight and turbidity developed shortly thereafter. The turbidity increased with time and a large number of microstructures formed in the mixture.

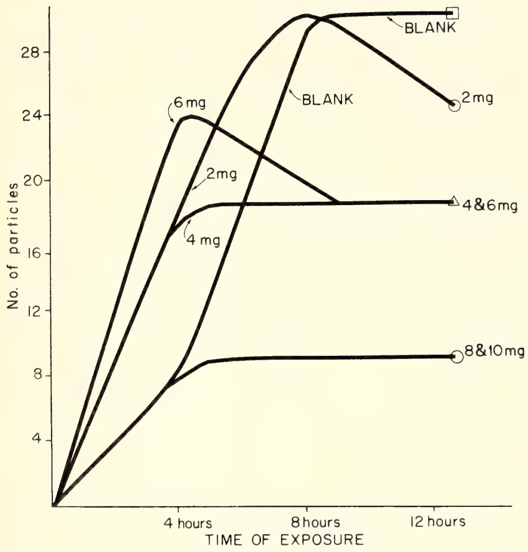


Figure 1. Effect of different concentration of Chloramphenicol on the formation of self-sustaining coacervates.

COUNTING OF PARTICLES

After exposure for four hours to sunlight all the mixtures were stored and the particles were examined microscopically. The particles were counted with a haemocytometer. Four slides of each mixture were prepared by taking one drop of the mixture aseptically from the test tube by glass rod. The counting of the particles are done under oil immersion microscope at 1,000 magnification. The number of particles in 10 different views at different places on the slide were counted within a specific area as marked in the eye piece. Thus, 40 counts in four slides for each mixture were taken. The counting of the particles formed in each mixture was performed after each four hours of sunlight exposure of each day.

OBSERVATIONS.

The results are shown in Table 1.

RESULTS

There was an increase in the number of particles after 4 hours exposure in the mixtures which had 2, 4 and 6 mg of chloramphenicol. In the mixture which had 2 mg of chloramphenicol, this increase continued and became comparable with the number of particles in the control mixture, but the number of particles did not increase on further exposure in the mixture which contained 4 mg of chloramphenicol. The number of particles in the mixture which had 6 mg of chloramphenicol was maximal at 4 hours exposure, but subsequently

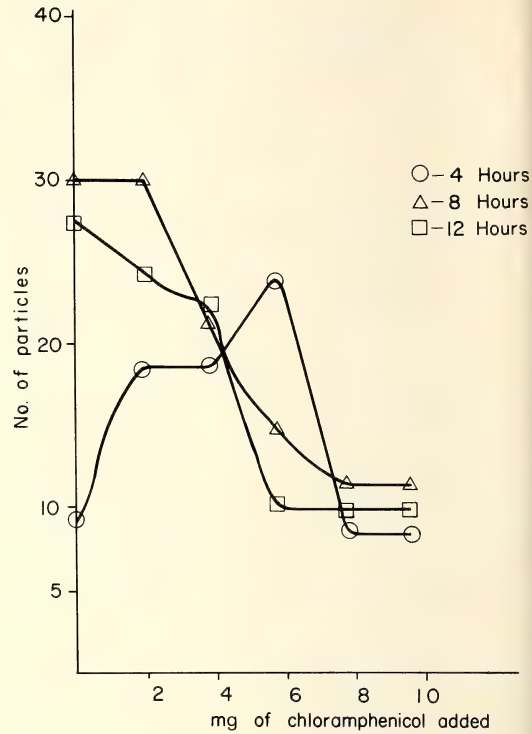


Figure 2. Number of particles as observed after 4, 8 and 12 hours of exposure.

the number of particles decreased rapidly (Figures 1 and 2). In the mixture containing high concentrations of chloramphenicol, i.e., 8 mg or 10 mg, the number of particles is the same as in the control during the first 4 hours of exposure. After this there was no significant increase in the number of particles with further exposure.

DISCUSSION

Thus, it has been observed that low concentration (i.e. up to 6 mg) of chloramphenicol in the mixtures which form self-sustaining coacervates on irradiation to sunlight increases the formation of these particles while larger concentrations (8 mg - 10 mg) do not affect the formation of particles during the first 4 hours of exposure. On further exposure, the number of particles became equal to the control in the mixture which had just traces (2 mg) of chloramphenicol. In the mixture having higher concentrations of antibiotic, the number of particles did not increase and was much less than the control.

TABLE 1

EFFECTS OF CHLORAMPHENICOL CONCENTRATION AND TIME OF EXPOSURE ON NUMBER OF PARTICLES

Reaction mixtures: 2 ml 4% ammonium molybdate solution + 4 ml 3% diammonium hydrogen phosphate solution + 2 ml mineral salts solution + 0.2 - 1.0 ml 1% chloramphenicol solution + distilled water to 9 ml total volume + 2 ml 36% formaldehyde solution.

| Weight for chlor-amphenical in reaction mixture (mgs) | Number of Particles at different exposure times | | |
|---|---|---|---|
| | 4 hours | 8 hours | 12 hours |
| 0 | 9.3 ± 1.08 | 30.35 ± 2.03 | 27.8 ± 1.13 |
| 2 | 18.9 ± 1.02 | 31.95 ± 1.9 | 24.6 ± 1.4 |
| 4 | 17.1 ± 2.4 | 21.3 ± 1.69 | 22.6 ± 2.1 |
| 6 | 24.3 ± 2.08 | 15.2 ± 1.8 | 10.3 ± 1.0 |
| 8 | 10.6 ± 1.4 | 13.6 ± 1.1 | 13.1 ± 0.8 |
| 10 | 13.9 ± 1.04 | 16.1 ± 1.8 | 16.2 ± 3.5 |

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# Polymers, Plastics and Fibres: The Old and The New*

DONALD H. NAPPER

ABSTRACT. This is the age of polymers: already the production of polymers for plastics, fibres, rubbers and surface coatings exceeds that of copper or aluminium and it is projected that even the production of steel will be outstripped in this decade. The unique properties that differentiate polymers ('giant molecules') from conventional small molecules are discussed. Case histories of the invention of some of the more important plastics (e.g., polythene) and fibres (e.g., nylon and terylene) are presented.

## INTRODUCTION

Historal eras have often been characterized by the materials that were extensively fashioned into implements and objects during those times: e.g., the Iron Age and the Bronze Age. Using this criterion, the current era might be termed the 'Plastics Age' or, more correctly, the 'Polymer Age'. Already a greater volume of polymeric materials is being produced than either copper or aluminium; furthermore, it is projected that in this decade, even the production of steel will be outstripped and that, by the turn of the century, the total production of all metals will be surpassed (Challis, 1978).

Fig. 1 displays the production of the more important plastics in the major Western nations (Allen, 1978). To obtain the total polymer production, however, it is necessary to add to these figures the tonnages of polymer produced for synthetic rubber (8 million tonnes in 1976), fibres, paints and adhesives. This, incidentally, ignores completely the exploitation of natural polymers (e.g., cellulose, still the most important of all fibres, and natural rubber).

The scale of the polymer industry can perhaps be grasped when it is appreciated that something like half of the chemists in the U.S. are concerned with macromolecules (Johnson and Richards, 1976). This is consistent with the fact that in the U.K., polymers account for about half of the total organic chemicals industry (Allen, 1978).

Virtually no aspect of our everyday (and not so everyday) lives is immune from polymers: from the humble nylon hair comb to the use of teflon prostheses and teflon by-pass tubing in heart surgery; from the synthetic fibres (e.g., polyesters) that give 'easy-care' fabrics to the new polyester bottle that is the first plastic container in Australia for carbonated beverages.

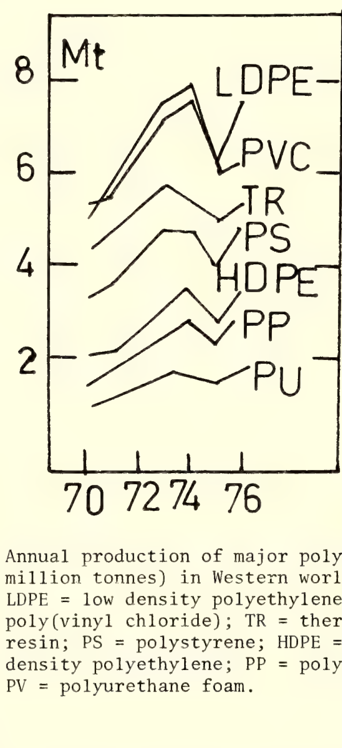



Fig. 1. Annual production of major polymers (in million tonnes) in Western world. Key: LDPE = low density polyethylene; PVC = poly(vinyl chloride); TR = thermosetting resin; PS = polystyrene; HDPE = high density polyethylene; PP = polypropylene; PV = polyurethane foam.

## POLYMERS

The bases of all plastics, fibres, rubbers and paints are polymers. The word 'polymer' was coined by Berzelius (1833) from two Greek words: 'poly' meaning 'many' and 'mer(os)' implying 'parts'. Polymers are defined as high molecular weight compounds whose structure consists of regularly repeating units, or chemically similar units, bound by primary covalent bonds. A simple analogy would be a string of beads. Some of the commercially more important polymers are shown in Fig. 2. The regularly repeating molecules that combine to form polymers are termed 'monomers' (M):

$$nM \rightarrow \left( M \right)_n$$

* *Presidential address delivered to the Royal Society of New South Wales at Science House; Clarence Street, Sydney on April 2, 1980.*

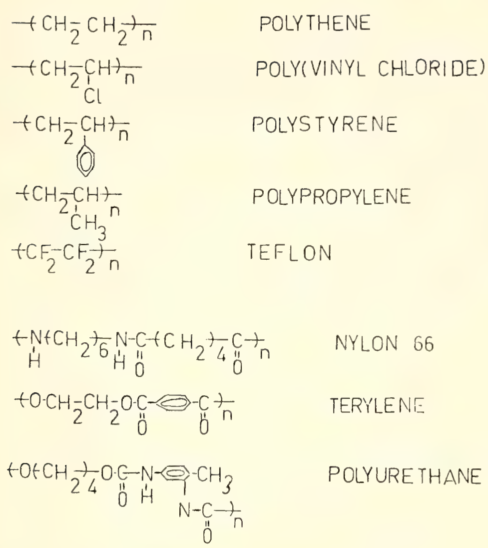



Fig. 2. Some important polymers

The molecular weights of commercially useful polymers lie in the range $10^3$ - $10^7$. This range is significantly larger than the molecular weights of the usual molecules of chemistry, which rarely exceed a few hundred. The high molecular weights of polymer molecules implies that their size is very large ('giant molecules'); so large, indeed, that Staudinger (1923) coined the term 'macromolecule' for them. Some insight into their massive size can be gained by representing the diameter of a typical atom (*ca.* 0.3 nm) by 1 cm of length: on this scale, most of the usual molecules of chemistry would be no larger than a soccer ball; polymer molecules of even modest molecular weight, however, would reach, say, 1 km if fully extended.

One crucial feature that distinguishes macromolecules from minimolecules is their molecular size. This, coupled with the articulation of the segments that results in the flexibility of the polymer backbone, imparts to macromolecules those special physical properties (e.g., elasticity, plasticity) that have allowed them to be exploited so widely.

Although the concept of high molecular weight species is accepted nowadays without question, this has not always been the case. Indeed, the acceptance of the concept of macromolecules is quite recent. In the early decades of this century, it was widely held that there was an upper limit of several thousands to molecular weights. Higher molecular weight species were believed to be generated by the physical association of these low molecular weight compounds (the 'micelle' theory). Hermann Staudinger, universally acclaimed as the father of polymer science, proposed in 1920 that polymers were true high molecular weight compounds. Yet as late as 1928, Wieland, a noted organic chemist who was a colleague of Staudinger's at the University of Freiberg, wrote to him: "Drop this business of big molecules; there are no organic molecules with a molecular weight of more than 5 000". The reluctance with which chemists accepted the concept of macromolecules is reflected in the fact that Staudinger was not awarded his Nobel Prize for the concept of polymers until 1953, when he was aged 72 and some 30 years had elapsed from when he made his original proposal.

## TYPES OF POLYMERS

Polymer molecules display great diversity and so they can be classified in a large number of ways. Some of these are related to how the polymer is prepared, others to the molecular architecture and the properties that it bestows.

Natural polymers are those found in Nature (e.g., cellulose in cotton) whereas synthetic polymers are man-made (e.g., terylene, polyurethanes). Derived polymers are those natural polymers that have been chemically modified (e.g., cellulose acetate).

Some of the possible variations in molecular architecture are shown in Fig. 3. The backbone of a polymer molecule can be linear or branched. If branched, the pendant chains may be long or short (as in low density polyethylene). A polymer molecule with a large number of long chain branches is termed a 'comb' polymer. Branching is important because it may profoundly influence the properties of the polymer (e.g., its degradative stability). Even more exotic structures, such as those of the ladder, step- and spiro-ladder polymers have been prepared. Catenane ladder polymers are also known.

The stereochemical properties of a polymer can also profoundly influence its behaviour. This is illustrated in Fig. 4 by polypropylene: two ordered structures, isotactic and syndiotactic, are

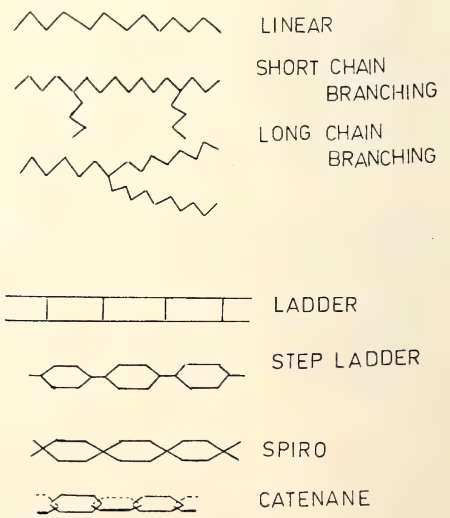



Fig. 3. Polymer architecture

easily recognized but in addition the random atactic polymer can also be prepared. Only isotactic polypropylene is exploited commercially (e.g., the dashboards of cars), the atactic polymer having no useful properties to-date.

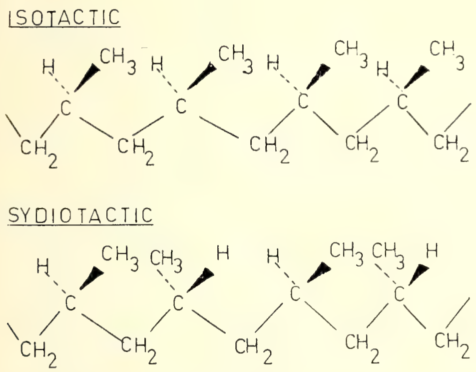



Fig. 4. Types of polypropylene

Polymers that soften and become plastic on heating but revert to a more rigid solid state on cooling are termed thermoplastic materials. Most of the common plastics of everyday use are thermoplastic (e.g., polystyrene, PVC). The onset of plasticity on heating occurs at the glass transition temperature $T_g$; it is a reversible physical process rather than a chemical change. Thermosetting polymers, on the other hand, are moulded irreversibly by chemical reaction at high temperatures, forming an infusible 3-D space network (e.g., the phenol-formaldehyde resin Bakelite). Thermosetting polymers would thus be difficult to recycle in comparison with thermoplastic polymers.

Polymers containing two or more monomers are also readily prepared. The monomer units in such copolymers may be linked in a random way or in an ordered fashion: in the latter case block, graft and alternating copolymers have been prepared (see Fig. 5).

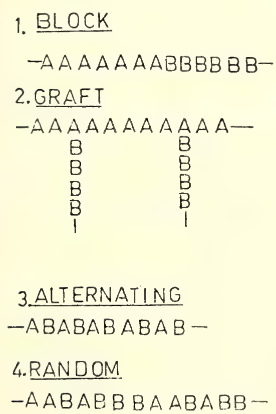



Fig. 5. Types of copolymers

Both the molecular architecture and the chemical composition of a polymer determine its final properties. There is a great diversity of molecular architecture and an almost unlimited number of monomers with a very broad span of physical and chemical properties. Consequently, it is in principle possible to tailor-make polymers with any desired properties although, at present, our knowledge is too incomplete for this to be achieved often.

THE PREPARATION OF POLYMERS

Polymer molecules are usually prepared by one of two methods: addition polymerization or condensation polymerization. In addition polymerization, the monomer units are covalently linked together without the elimination of a low molecular weight species. This contrasts with condensation polymerization where a low molecular weight species (e.g., $H_2O$, HCl) is eliminated.

Three stages are recognized in addition polymerization, which commonly may proceed by a free radical, anionic or cationic mechanism. First, there is the initiation of the active species, which may be a free radical, carbonium ion or a carbanion:

$$M + I \rightarrow M^*$$

where M is the monomer, I is the initiator and $M^*$ is the reactive monomeric species. The latter adds on monomer progressively in the propagation step to produce species of high molecular weight:

$$M^* + M \rightarrow M_2^*$$

$$M_2^* + M \rightarrow M_3^*$$

................

$$M_n^* + M \rightarrow M_{n+1}^*$$

................

Typically, one thousand monomers would be added per second. Ultimately, the propagating species is usually terminated by some annihilation step, e.g. radical recombination reactions. However, in anionic polymerizations performed under rigorously pure conditions, the carbanions, which cannot recombine due to Coulombic repulsion, may be stable indefinitely, even after all the monomer has been consumed. Addition of further monomer will result in additional growth of the polymer chains, which will again become inactive once the monomer is consumed. Such polymeric anions are referred to somewhat picturesquely as 'living polymers', for they will grow almost indefinitely if supplied with monomer.

SOME CASE HISTORIES OF THE DISCOVERY AND INVENTION OF POLYMERS

Celluloid

The first synthetic plastic to be exploited commercially was celluloid, the derived polymer cellulose nitrate. This is prepared from cellulose (e.g., cotton linters) by nitration in the presence of sulphuric acid until there are, on average, 2.4 nitrate ester groups per pyranose ring.

In the 1860's there was a shortage of ivory billiard balls in the U.S.A. due to the decimation of the elephant herds of Africa. A prize of $10 000 for the development of a substitute for ivory in billiard balls, led a journeyman printer, John Wesley Hyatt, regarded as the founder of the plastics industry, to attempt to devise a suitable substitute. Legend has it that during this work, he cut his finger and went to the medicine cabinet for some collodion (cellulose nitrate dissolved in ethanol and ether). The bottle had tipped over, spilling its contents which had hardened to a rubbery mass. Hyatt recognized the material to be what is now termed thermoplastic for when he rubbed it between his fingers it softened.

Hyatt soon showed that camphor plasticized cellulose nitrate (i.e., it lowers $T_g$) and that celluloid could replace hard rubber in dental plates. So the first plastic was born. The term 'plastic' was not, however, coined until 1914.

Celluloid was used for a variety of applications of which the backing of films in photography is one that springs readily to mind. It is, however, a close relative to nitrocellulose (the basis of dynamite), which is the fully nitrated cellulose. Not surprisingly, celluloid is highly inflammable and this, coupled with its inability to be injection moulded, has led to its eclipse as a plastic, although it still finds some specialty uses as in, e.g., ping-pong balls.

It might be noted in passing that one way around the extreme flammability of the nitrate ester groups in celluloid is to circumvent the nitrate ester group by esterifying with acetic acid. This gives rise to cellulose acetate, which is useful both as a moulding material (e.g., toothbrush handles) and as a fibre (these contain on average 2.4 and 3 ester groups respectively per pyranose ring).

Polythene

Polythene is currently the largest selling plastic in the world. It is perhaps the plastic most familiar to the non-technologist. Its discovery is interesting in that it illustrates the importance of serendipity in scientific research. In 1933, two chemists, Gibson and Fawcett, at the Alkali Division of ICI were conducting fundamental research into the effects of very high pressures on a number of liquid/gas reactions. One of those studied was that of benzaldehyde with ethylene at 1300 atm and 170 $^{o}$C. This resulted in a 'white waxy solid' that on analysis was found to contain no oxygen from the benzaldehyde and so it was recognized to be the polymer of ethylene. To confirm this, the experiment was repeated with ethylene alone whereupon a violent explosion occurred, smashing the guages. The work was then abandoned.

It was, however, taken up again in 1935 by Perrin and Williams with stronger and safer equipment. Polymerization was found to proceed smoothly at high pressures (e.g., 2000 atm). Again, however, there was an element of chance. The apparatus was leaky and sufficient oxygen had been introduced inadvertently into the ethylene to act as a free radical initiator, without which the polymerization would not have proceeded.

Polyethylene is a versatile polymer being used for a wide range of applications, e.g., as squeeze bottles, sheeting and in insulation.

The polythene produced by the foregoing procedure is termed high pressure, low density polythene (LDPE). In 1953, Professor Karl Ziegler, at the Max Planck Institute, Mulheim, showed that ethylene could in fact be polymerized at ambient pressure provided that the catalyst was carefully chosen. The product obtained is, however, quite different from that generated at high pressures. Whereas LDPE has a low crystallinity (*ca.* 50%) and low density ($\leq$ 0.94 g cm$^{-3}$), the low pressure polymer has a high crystallinity (> 90%) and high density. These differences arise from differences in molecular structure: polythene prepared by the Ziegler procedure contains linear polyethylene molecules whereas the LDPE material contains chains that exhibit short chain branching. The branches are primarily butyl side chains, and they occur with a frequency of 1 per 50 $-CH_2-$ residues, as a result of a 'back-biting' process.

Polypropylene

The year after Ziegler's discovery, Professor Natta of Milan Polytechnic Institute showed how propylene could be polymerized to isotactic polypropylene by using catalysts similar to those of Ziegler. Such catalysts, which are a complex mixture of the halides of transition metals and organometallic compounds, have come to be known as Ziegler-Natta catalysts. Ziegler and Natta shared the Nobel Prize for Chemistry in 1963 for their discovery of these catalysts, which are capable of the stereospecific polymerization of many monomers. They are, incidentally, the only really successful catalysts for polymerizing propylene. Its polymer is the lightest of the major commercial plastics (density = 0.905 g cm$^{-3}$). This, coupled with its excellent mechanical properties (e.g., tensile strength, rigidity) and the fact that it can be spun into a fibre, will ensure an expansion in the uses of polypropylene. Its flammability as a fibre, however, should not be overlooked.

Teflon

Teflon is polytetrafluoroethylene. It has occasionally been stated in the local media that non-stick frypans are a spin-off from space exploration. Whilst it is true that polymers that withstand temperatures in excess of several thousand degrees have been developed as heat shields on space vehicles, teflon was discovered, again somewhat accidentally, in 1938 by Plunkett, working for Kinetic Chemicals (later taken over by Du Pont).

Plunkett had a cylinder of tetrafluoroethylene in which the pressure dropped. He recognized that one possible explanation for this reduction in pressure could have been the polymerization of the gas, akin to the high pressure polymerization of ethylene. On cutting the cylinder open, Plunkett found a white powder composed of polytetrafluoroethylene. Again, sufficient impurity oxygen was

present to initiate polymerization.

Teflon has one of the lowest coefficients of friction of any solid known (*ca.* 0.02) so it is useful in bearings where lubrication is undesirable. This, coupled with its excellent temperature stability (up to 300 °C), renders it useful as a non-stick coating in kitchenware.

## Nylons

Unlike several of the discoveries mentioned above, the nylons, which were the first synthetic fibres, were the product of inspired chemical thinking by W.H. Carothers. He had joined Du Pont in 1928 to work on the synthesis of high molecular weight compounds, the accepted world record at that time being a little over 4000. Carothers recognized that one of the limitations on the formation of higher molecular weight compounds by condensation reactions of difunctional compounds was cyclic ring formation. Carothers therefore explored the condensation of molecules of the type xAx with yBy, where x and y are reactive functional groups and A and B are molecular spacers (e.g., $(CH_2)_6$):

$$n\ H_2N(CH_2)_6NH_2 \quad + \quad n\ HOOC(CH_2)_4COOH \quad \rightarrow$$

hexamethylene diamine      adipic acid

$$H\left[\overset{H}{\overset{|}{N}}(CH_2)_6\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}(CH_2)_4\overset{O}{\overset{\|}{C}}\right]_n OH \quad + \quad (2n-1)H_2O$$

nylon 66

Poly(hexamethylene adipamide) is also known as nylon 66, the first of the two numbers representing the number of carbon atoms in the diamine whilst the second represents the number in the diacid. Nylon 66 came onto the market in 1938 as toothbrush bristles. In the following year, the first nylon stockings became available and, within twelve months, 64 million pairs were sold. Other nylons that are commercially important (although to a lesser extent) are nylon 6 10, nylon 6 and nylon 11. For the last two nylons, the polyamide is formed by the self-condensation of the appropriate amino acid (e.g., ε-aminocaproic acid), highlighting the fact that nylons are the synthetic analogue of proteins. Common uses of nylons are in tyre cord, wearing apparel and carpets.

## Polyester

Carothers in his studies that led to the development of polyamides had also investigated high molecular weight aliphatic polyesters:

$$n\ HOCH_2CH_2OH \quad + \quad n\ HOOC(CH_2)_4COOH \quad \rightarrow$$

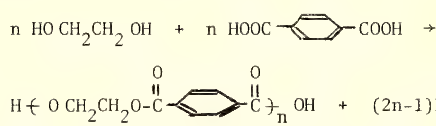
ethylene glycol      adipic acid

$$H\left[O\text{-}CH_2CH_2\text{-}O\text{-}\overset{O}{\overset{\|}{C}}\text{-}(CH_2)_4\text{-}\overset{O}{\overset{\|}{C}}\right]_n OH \ + \ (2n-1)H_2O$$

These polyesters were microcrystalline and capable of being extruded into fibres. 'Time' magazine heralded their discovery as follows: 'The fibre is as lustrous as silk, stronger than and more elastic than rayon and as strong and as elastic as real silk'. What the report failed to mention was that their melting point was too low, their hydrolytic stability poor and their solubility too great in organic solvents.

The melting point $T_m$ for a polymer is given by the usual thermodynamic expression $\Delta H_m/\Delta S_m$, where $\Delta H_m$ and $\Delta S_m$ are the corresponding enthalpy and entropy changes. A stiff polymer, e.g., one containing the inflexible benzene ring, will have a smaller entropy change on melting (due to a smaller disorder in the liquid state) than a flexible one, such as one made from aliphatic polyesters. Its melting point will therefore be greater than that of the aliphatic polyester. In addition, crystallinity will increase $\Delta H_m$ and thus the melting point. Carothers had looked briefly at aromatic polyesters, using the unsymmetrical phthalic acid, without success.

Two British chemists, Whinfield and Dickson, of the Calico Printers Association, in 1941 recognized that the key to crystallinity and fibre structure lay in molecular symmetry. They therefore condensed the symmetrical terephthalic acid with ethylene glycol to produce terylene, poly(ethylene terephthalate):

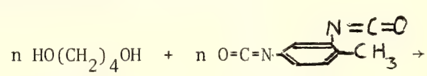


The aromatic polyester has a melting point of *ca.* 270 °C compared with the corresponding value of 50 °C for the aliphatic adipates.

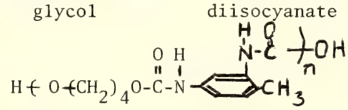
Fibres of polyester have good wrinkle resistance and so are exploited in easy-care fabrics. In some uses, however, terylene is blended with a more hydrophilic fibre (e.g., wool or cotton) because in dry climates the pure polyester retains too little moisture and a garment made from it becomes too highly charged electrically.

## Polyurethanes

A second class of polymers that was developed as an extension of Carothers' polyamides is the polyurethanes. Bayer in Germany in 1939 discovered that diisocyanates and diols were capable of undergoing polyaddition reactions:

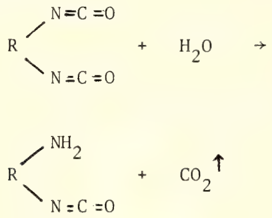


tetramethylene glycol      toluene-2:4 diisocyanate



polyurethane

Polyurethanes are used in coating and elastomeric applications but are perhaps best known as foams. The foams are easily generated by the reaction of the diisocyanate with water to produce carbon dioxide:

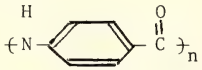


The structure of the foams produced may be of an open or closed cell type: an open cell foam is, e.g., able to soak up a considerable volume of water into its cells and so is useful as a sponge whereas closed cell foams are useful as cushions in upholstery. The C - N bond in polyurethanes, however, is something of a problem in the event of a fire because at high temperatures it results in the production of the lethal gas HCN (used by some states in the USA for gas chambers). The use of polyurethane foam cushions in aeroplanes may, therefore, be outlawed in some countries.

Polyaramides

Linear macromolecules lose their desirable characteristics as soon as degradation (chain scission) becomes extensive. Early in the history of thermally stable polymers, the prediction was made that double stranded, ladder polymers (see Fig. 3) would display greater thermal stability than single stranded polymers. Any rupture in a single strand chain is effective in reducing the polymer molecular weight; in contrast, cleavage of two bonds in the same connecting ring is necessary to cause such a decrease in a ladder polymer. The predictions of good thermal stability of ladder polymers has been amply verified experimentally. It is easier, however, to prepare step-ladder than ladder polymers and some of these, e.g. aromatic polyamides, have proved to be commercially useful. Note that nylons, aliphatic polyamides, are not step-ladder polymers.

Kevlar fibres (Du Pont) are usually considered to be poly(p-benzamide):



although IR evidence suggests that they might be poly(p-phenyleneterephthalamide). These fibres are self-extinguishing and their use in US Air Force flying suits is mandatory. Their excellent mechanical properties (e.g., an exceptionally high modulus that is greater than that of glass fibres) mean that they are eminently suitable for use in reinforced plastics. The sails carried by the successful defenders in the recent America's Cup series have been made from Kevlar; Australian challengers will not be able to use these sails in this race until the fibre is manufactured in this country.

Some Other Polymers

The histories of several of the high volume polymers is rather more prosaic than those set forth above, being histories of neglect and oversight. Polystyrene, e.g., was actually discovered in 1839, only eleven years after Wöhler laid the foundations of synthetic organic chemistry by preparing urea in the laboratory. The monomer was first prepared by Simon, a German apothecary, from a resin derived from a tree (*Liquidambar orientalis*) found in Asia Minor. He showed that styrene on heating solidified, which he attributed to an oxidation reaction. This was disproved in 1845 by two English chemists, Blyth and Hoffman, who showed that the solid had the same composition as the starting material. It was left to Staudinger some eighty years later to appreciate the true nature of the polymerization product. It should be appreciated that organic chemists in the nineteenth and early twentieth century regarded any substance that could not be crystallized or which did not have a sharply defined melting point as a waste product and the experiment that produced it as a failure. Many polymers fell into these categories.

The production of polystyrene was not commercially viable until 1930, being dependent upon the development of a method for manufacturing the monomer cheaply. The same limitation applied to the exploitation of poly(methyl methacrylate) as an 'organic glass'. Glass-like polymers of acrylic esters were first reported by Fittig in 1877 but it was not until 1933 that ICI produced the first cast acrylic sheet from monomer manufactured from cheap, readily available chemicals.

Vinyl chloride is another monomer that languished on the laboratory shelf for almost a century. The monomer was discovered by Regnault in 1835 and its polymerization was reported by Baumann in 1872. Commercial exploitation of PVC did not commence until the 1930s.

SOME FUTURE PERSPECTIVES

A very large number of monomers and their corresponding polymers have now been examined by polymer chemists. This type of research has currently lost some of its impetus so that while new polymers for specialty uses seem likely to be developed (e.g., for the optoelectronics industry, biomedical applications), it is unlikely that new bulk polymers will be manufactured in the near future.

The trend away from the study of the chemistry of monomers and polymers has been paralleled by an upturn of research into the physical and mechanical properties of polymers and into polymer engineering. Already aromatic and heterocyclic monomers can produce fibres with the strength and rigidity of steel but with only 15% of the weight. Some small suspension bridges already use cables made from strong, polymeric filaments. If a lightweight, carbon-fibre reinforced thermosetting resin was used for the body of the bridge, instead of steel, much wider spans would be possible. It also seems likely that future developments in the exploitation of polymers will be associated with an improved understanding of the properties of composites and of phase-separated block and graft polymers.

The importance of polymer engineering cannot be overemphasised. When plastic materials are found to warp or crack in service, the blame is usually attributed to the plastic. Most of these failures, however, can be traced to inadequacies of design and processing rather than the material performing less well than idealised test pieces. Plastics are difficult, unforgiving materials to design in. They are fairly weak and have a relatively low modulus compared with metals. Against this, they are easy to fabricate and plastic articles have a low total energy embodied in them (e.g., the energy required to produce a plastic bottle is only about one-third of that of a glass bottle). Consequently, plastics are competitive materials and are likely to remain so, even if there is a shortage of oil in the future. Polymer production utilizes only a few percent of the total oil production to-day. The use of high-strength, lightweight plastics is already resulting in improved automible fuel economy. Conversion to a coal-based feedstock would be a relatively simple operation; the German chemical industry was coal-based in the past. An alcohol based feedstock would also be possible if a renewable source were required.

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The University of Sydney,
Sydney N.S.W. 2006

To conclude, we recall the prophetic words of Leo Baekeland, the inventor of Bakelite, on the occasion of the award to him in 1938 of the Messel Medal of the Society of Chemical Industry: "The whole fabric of modern civilization becomes every day more interwoven with the endless ramifications of applied chemistry". Polymers are clearly one of the more important examples of the fruits of applied chemistry.

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# JOURNAL AND PROCEEDINGS

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# A Vessel Positioning Method for Surveys in Coastal Waters

ALBERTO ALBANI

ABSTRACT. A simple and precise system for positioning a vessel engaged in surveys of coastal waters is presented. The vessel position can be obtained either graphically or numerically using coordinates; both resection and intersection methods can be applied. The method is based on the use of a 35mm camera.

## INTRODUCTION

One of the basic difficulties found in surveys of coastal waters is the precise positioning of the survey vessel at any given time. This problem is particularly felt during bathymetric and seismic investigations with the vessel being underway during position fixing.

The availability of electronic devices has solved the problem, however there are times when simple and inexpensive methods are desirable; sextant fixing (horizontal angles) (Green, 1967) is the most commonly used, followed by theodolite positioning from shore based stations; the latter method, although very precise, requires at least three operators and radio communication.

The position fixing here presented is simple, shipborne and, at the same time, it requires only one operator. Its precision is superior to that of the sextant method with the approximation in angles determination of the order of ±4',which corresponds to a linear accuracy of 2-3 metres at a distance of 2 km (0.57mm at a scale of 1:4000; 0.23mm at a scale of 1:10,000).

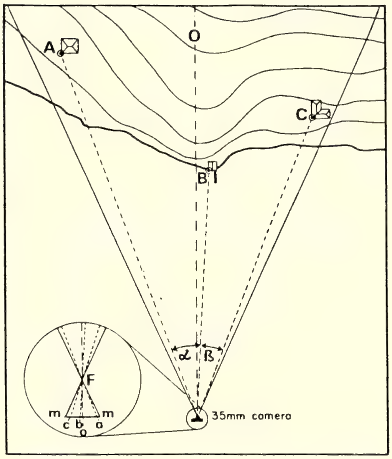


Fig. 1. Geometric relationship between the terrain and its photographic image.

## METHOD

The method described is based on well known photogrammetric techniques (Albani, 1973; American Soc. Photogrammetry, 1966); a 35mm camera with good optical system forms the basic requirement. In Figure 1 the main principle of the method is illustrated: the points A, B, C represent details visible from the survey vessel and also identified on the base map, as in the case of the sextant method; their images are formed on the camera film at a, b, c with F being the focal point of the optical system and oFO the optical axis. The angles α and β are related, on the film, to the distance between the images of the various points; the camera being always focussed at infinity.

As measurements on the 35mm slide, or negative, are not practical using simple equipment, best results have been obtained using a slide projector equipped with a good quality projection lens. The slide is projected on a transparent rigid screen (Fig. 2) placed at right angles to the optical axis. The use of a transparent screen allows measurements to be taken at the back of the screen itself without interfering with the projection of the slide.

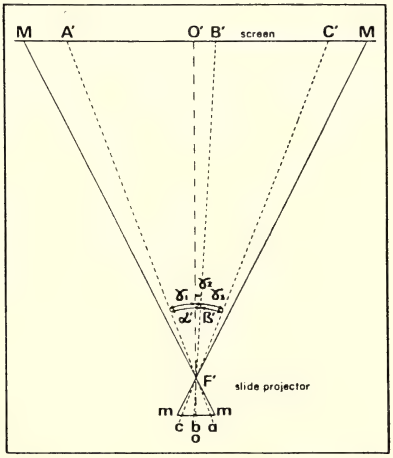


Fig. 2. Relationship between the photographic image and its projection on the screen.

The angles α and β are proportional to the angles α' and β', and these in turn are related to the distances A'B' and B'C' (Fig. 2). The angles α' and β', and consequently α and β, can be

expressed in function of the angles $\gamma_1$, $\gamma_2$, $\gamma_3$ that the points A', B' and C' make with the optical axis:

$$\alpha' = \gamma_1 + \gamma_2; \quad \beta' = \gamma_3 - \gamma_2 \qquad (1)$$

The angles $\gamma_1$, $\gamma_2$ and $\gamma_3$ can be obtained from:

$$\tan \gamma_1 = \frac{O'A'}{O'F'}; \quad \tan \gamma_2 = \frac{O'B'}{O'F'};$$
$$\tan \gamma_3 = \frac{O'C'}{O'F'} \qquad (2)$$

Although the exact position of o (and O') is not known, it is assumed, for all practical purposes, to be located in the centre of the slide identified by half the distance between the printed margins m (Fig. 3).

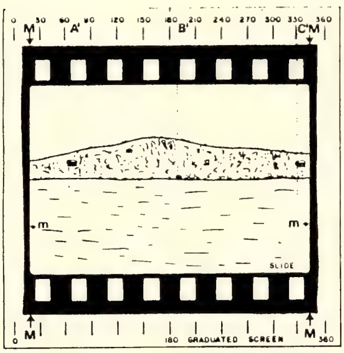


Fig. 3. Image of the terrain as projected against the graduated screen.

An error in the position of o of even 1mm, (3%) within the 35mm slide, produces an angular difference less than 1 minute between points located at the two extremes of the photograph. In the several camera-lens systems tested by the author the asymmetry in the position of the optical axis has been found to be less than 0.5%. Such error is compensated in the determination of the constant K.

In order to minimize the optical distortions, the photograph, generally taken from a vessel and therefore only from a few metres above water level, should be horizontally halved by the shore line, thus making the optical axis very close to be horizontal. Even in choppy conditions this is very easily obtained, certainly much more easily than measuring angles with a sextant.

To solve the formulae (2) the value O'F' is necessary and it is determined within the calculation of the constant K. The value O'F' is related to the focal length of the camera lens, the focal length of the projector lens and to the enlargement, that is, the distance between the screen and the projector.

Once the constant K is determined, using a small programmable calculator and entering the values for A', B', C', read on the screen, the angles $\alpha$ and $\beta$ are directly obtained using the formulae (4) and (5).

To simplify the determination of $\alpha$ and $\beta$, the author has graduated the screen; the slide, mounted between glass, must show, when projected, the printed margins m as these are used to center it with respect to the screen itself (Fig. 3). The reference marks M, on the screen, represent the position of the margins m, of the slide, for the selected enlargement. The vertical plane containing the optical axis will be then located in the centre of the graduation (180, Fig. 3).

DETERMINATION OF THE CONSTANT K

The success and precision of the method rests primarily in the accuracy in determining the value of the constant K for the selected camera-projector system.

Several variable parameters are present in such constant and their total effects are included in its value. The most important of these parameters are: the value of O'F', the proportion factor between $\alpha$, $\beta$ and $\alpha'$, $\beta'$ and finally the asymmetry of the optical axis of both camera and projector.

The most accurate procedure is to select a land based station which offers a view containing a large number of easily identifiable details. From the selected land station a series of photographs are taken making sure that the camera is held with optical axis perfectly horizontal; this can be achieved by using a tripod with a level.

From this station a series of angles is then measured using a theodolite and sighting to as many details as possible. If the photographs taken are printed prior to the angle measurements, the detail which in the photograph is located in the vertical plane containing the optical axis can be identified and used as origin for the various angles.

The photographs are then projected against the graduated screen and the value of K is obtained from:

$$K = \frac{O'A'}{\tan \gamma_1^{1}} = \frac{O'B'}{\tan \gamma_2^{1}} = \frac{O'C'}{\tan \gamma_3^{1}}$$

using $\gamma_1^{1}$, $\gamma_2^{1}$, $\gamma_3^{1}$ (etc) determined by the theodolite observations and O'A', O'B', O'C' (etc) measured from the screen itself.

It is desirable to take a series of photographs with lenses of various focal length as to increase the flexibility of the field operation; each combination: camera lens-projector lens-enlargement, has a different value for the constant.

STATION POSITION FIXING

The angles $\alpha$ and $\beta$ can be obtained therefore from the distances O'A', O'B' and O'C' read from the graduated screen and using:

$$\tan\gamma_1 = \frac{O'A'}{K}\ ; \quad \tan\gamma_2 = \frac{O'B'}{K}\ ;$$
$$\tan\gamma_3 = \frac{O'C'}{K} \qquad (4)$$

$$\alpha = \gamma_1 + \gamma_2; \quad \beta = \gamma_3 - \gamma_2 \qquad (5)$$

Once $\alpha$ and $\beta$ are obtained the station position may be determined either graphically, as in the sextant method, or numerically by using the resection method from the coordinates of the points A, B and C.

The base map used may not always indicate the details selected on the photographs for the position fixing; however they can be accurately plotted on the map itself either through aerial photographs (Albani, 1964) or by using the method here presented with photographs taken from at least two shore stations, identifiable on the map, and by simple intersection.

The use of polaroid cameras and an appropriate transparent graduate screen to superimpose on the photograph may allow a more speditive use of this method; however the precision of the position fixing is greatly reduced.

During the many surveys in which this method has been employed the maximum plotting error was found to be well within the drafting accuracy of the base map used.

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# A Clast Fabric Paleocurrent Study of the Late Devonian Keepit Conglomerate, Northeastern New South Wales

T. G. Russell

ABSTRACT. Due to a scarcity of directional sedimentary structures in outcrops of the Late Devonian Keepit Conglomerate fabric studies were undertaken upon both the fluvial and the resedimented marine conglomerates of this formation with the primary aim of providing paleocurrent data.

AB plane orientation was found to be a more useful indicator of paleocurrent direction than A-axes, the latter typically being more variable in their orientation. Both the fluvial and resedimented conglomerates possessed in almost all instances a moderate to pronounced imbrication of the AB plane. The relationship of the vector mean to the inferred paleocurrent direction is not always one of agreement. Interpretation of the vector mean in terms of paleocurrent direction should always be done with reference to the fabric diagram.

Paleocurrent data obtained by fabric studies of the Keepit Conglomerate indicate individual flow directions ranging from east of north to south-southeast. Two anomalous samples indicate northwesterly directed paleocurrents. The fabric paleocurrent directions agree with other data in suggesting for the depositional basin during Keepit Conglomerate times a source area to the west, with sediment dispersal down an east-sloping paleoslope.

## INTRODUCTION

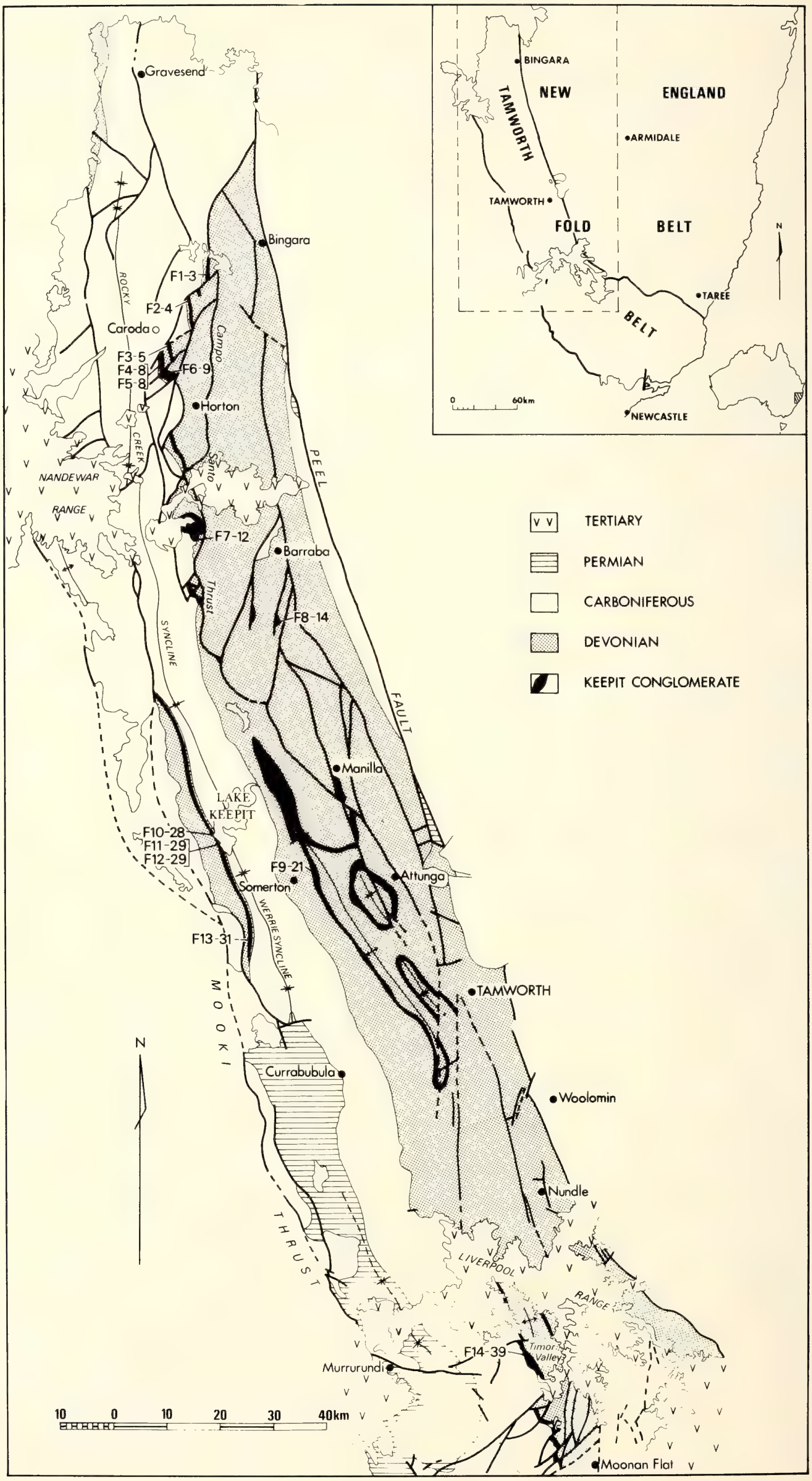
The Keepit Conglomerate is a Late Devonian coarse conglomerate unit occurring within the Devonian-Carboniferous marine sequence of the Tamworth Belt, northeastern New South Wales (Fig. 1). For most of its present day outcrop, the Keepit Conglomerate consists of massive, normal and inverse graded pebble to boulder grade clast and matrix supported conglomerates, normal graded pebble conglomerates and pebbly sandstones and graded sandstones, (proximal and thin bedded turbidites), together with mudstones and thin sandstones. Abraded crinoid, brachiopod and gastropod fragments occur in some of the conglomerate matrices and sandstones. The sedimentary structures and facies relationships of the conglomerates and sandstones indicate deposition by a variety of sediment gravity flows in submarine fan environments, while the mudstones and thin sandstones represent the background hemi-pelagic and bottom current sedimentation within the depositional basin (Russell, 1977, 1979b, in prep.). On the western limb of the Werrie Syncline (Fig. 1), nearest the basin margin, the Keepit Conglomerate consists mainly of massive to horizontally stratified pebble to boulder grade conglomerates, and sandstones. The conglomerates are predominantly clast supported and possess imbricate clasts and pebble clusters. The sand-stones, frequently lensoidal beds, are typically massive and/or parallel laminated, and less commonly cross stratified and rippled. Lensing and scour and fill relationships, with basal lag gravels in scours, are common. Mudstone is present typically as thin irregular layers in sandstones, and draping ripples and gravel surfaces. On the basis of the sedimentary structures, the absence of marine fossils, the basin margin location and the disconformable contact with the underlying marine mudstones (Russell, 1979a), the Keepit Conglomerate in this area is interpreted as the deposits of prograding alluvial fans constructed largely by braiding streams (Russell, 1977, 1979b, in prep.).

Directional sedimentary structures are not common in the Keepit Conglomerate. Fabric studies were therefore undertaken with the primary aim of providing paleocurrent data. The fabrics measured from the Keepit Conglomerate are original primary sedimentary fabrics, no evidence existing for later tectonic modification of these fabrics.

## CONGLOMERATE FABRIC STUDIES

### Introduction

The existence within gravels and conglomerates of an anisotropic fabric, and the relationship of this fabric to current direction, has long been recognised (Jamieson, 1860, p. 349; Becker, 1893, p. 54; Richter, 1932, 1933). Fabric studies of rudaceous deposits may therefore provide paleocurrent data for conglomerates frequently devoid of other directional structures (e.g., Laming, 1966; Nilsen, 1969; Nilsen and Simoni, 1973; Ryder and Scholten, 1973; Schlager and Schlager, 1973; McLean, 1977). Gravel fabrics may be readily measured due to the size of the fabric elements or clasts. Two aspects of the clasts are usually recorded; the dip and dip direction of the AB plane and the dip and azimuth of the A-axis. Techniques for the study of gravel fabrics, mostly relating to unconsolidated deposits, are reviewed in Potter and Pettijohn (1963, p. 28-31) (see also Rust, 1975). Fabric studies upon indurated deposits are more difficult and often measurement of only the apparent longest axis, A', (e.g., White, 1952; Schlee, 1957;



BINGARA
NEW
ENGLAND
TAMWORTH
ARMIDALE
TAMWORTH
FOLD
BELT
N
TAREE
BELT
0 60km
NEWCASTLE
Gravesend
Bingara
F1-3
F2-4
Caroda
Campo
F3-5
F4-8
F5-8
F6-9
Horton
ROCKY
CREEK
Santo
PEEL
NANDEWAR
RANGE
F7-12
Barraba
Thrust
SYNCLINE
F8-14
FAULT
TERTIARY
PERMIAN
CARBONIFEROUS
DEVONIAN
KEEPIT CONGLOMERATE
Manilla
LAKE
KEEPIT
F10-28
F11-29
F12-29
F9-21
Somerton
Attunga
WERRIE SYNCLINE
F13-31
M O O K I
TAMWORTH
N
Currabubula
Woolomin
Nundle
T H R U S T
LIVERPOOL
RANGE
F14-39
Timor Valley
Murrurundi
10 0 10 20 30 40km
Moonan Flat

Pettijohn, 1962; Lindsey, 1966; Nilsen, 1969; Nilsen and Simoni, 1973; Schlager and Schlager, 1973; Davies and Walker, 1974; Walker, 1975b; McLean, 1977) or, less commonly, the apparent maximum projection plane A'B' (e.g., Nilsen and Simoni, 1973; Rocheleau and Lajoie, 1974; Hendry, 1976; Walker, 1977a) is possible.

Fluvial gravel Fabrics

Fluvial gravel fabrics are widely documented, (e.g., Krumbein, 1939, 1940, 1942; Schlee, 1957; Unrug, 1957; Johansson, 1963, 1965; Sedimentary Petrology Seminar, 1965; Sengupta, 1966; Kelling and Williams, 1967; Katzung, 1971; Rust, 1972, 1975; Liboriussen, 1975; additional references are cited by Potter and Pettijohn, 1963, p. 35). The most obvious feature of fluvial fabrics is a strong upstream imbrication of the AB plane, reflecting the unidirectional flow. When plotted on a Schmidt net a prominent maximum exhibiting monoclinic symmetry results (e.g., Schlee, 1957; Potter and Pettijohn, 1963, Plate 1b; Sedimentary Petrology Seminar, 1965; Katzung, 1971). Instances of downstream imbrication are rare, and mostly result from clasts deposited upon foreset beds (Johansson, 1963, p. 110; Sengupta, 1966; Bandyopadhyay, 1971; Liboriussen, 1975). Measurement of the attitude of the AB plane is therefore considered to give a reliable indication of current flow direction. Rust (1975) has shown a close relationship between current directions indicated by clast imbrication and the mean orientation of surface channels and braid bar long axes for braided streams.

A-axis orientation in fluvial deposits is more variable and has thus been considered less reliable as a paleocurrent indicator (Schlee, 1957, p. 166; Johansson, 1965, p. 38-39; Sedimentary Petrology Seminar, 1965, p. 281; Liboriussen, 1975, p. 236). Rust (1972), however, considers the A-axis to be a reliable current indicator, especially when larger elongate clasts isolated upon sandy beds can be measured. The A-axis in fluvial gravel fabrics may parallel the flow direction and plunge upstream, may be transverse to flow, or may be both parallel and transverse to the flow direction. In this last instance, and especially if the maxima are less well developed, the A-axes plot on a stereographic projection as a girdle striking perpendicular to flow direction and dipping in an upcurrent direction (e.g., Schlee, 1957; Sedimentary Petrology Seminar, 1965; Katzung, 1971; Liboriussen, 1975). Interpretation of the relationship of the A-axis to the current direction depends in part upon the number and strength of the maxima, and the ability to distinguish the A parallel to flow from the A transverse to flow maxima. An upcurrent plunge of A when parallel to current direction may assist in this respect. The variable orientation of the A-axis has been attributed to a number of factors including the clast size and shape, the density of clasts in the deposit, the sandy or gravelly nature of the substrate, the angle of slope of the sedimentation surface, the method of clast movement, and the depth and velocity of the flow.

Resedimented Conglomerate Fabrics

Quantitative studies on the fabric of resedimented conglomerates are few. These were reviewed and summarised by Walker (1975a, Table 1) who concluded "when all the available data are studied, six out of seven examples show the long axis dipping upstream and parallel to flow" (Walker, 1975a, p. 742). Resedimented conglomerates not cited by Walker and exhibiting A-axes parallel to flow direction were described by Wieser (1954) and Ksiazkiewicz (1958, p. 130). However, both Piper (1970) and Rupke (1975, 1977) have described resedimented conglomerates in which A-axes are oriented transverse to flow direction. Mudflow fabrics have been studied by Lindsay (1964, 1966, 1968) and Lindsay *et al* (1970). Lindsay (1968, p. 1249) states "The most distinctive feature of the mudflow A-axis fabrics is the (upcurrent) dipping girdle". An A-axis parallel to flow direction fabric has also been described from avalanche boulder tongue deposits by Rapp (1959), and from Triassic alluvial fan mudflow deposits by Bluck (1965).

Where measured, the AB planes of clasts in resedimented conglomerates are imbricate upcurrent (e.g., Moors and Schleiger, 1971; Nilsen and Simoni, 1973; Rocheleau and Lajoie, 1974; Walker, 1975a, p. 741, 1977a; Hendry, 1976; Winn and Dott, 1979). This preferred orientation of the AB plane in resedimented conglomerates may be utilised in paleocurrent studies. Caution, however, should be exercised when inferring paleo-current directions from A-axis orientations.

A CLAST FABRIC PALEOCURRENT STUDY OF THE KEEPIT CONGLOMERATE

Methods

A total of 14 localities from 12 measured sections were the subject of fabric studies (Fig. 1, Appendix). Each locality was selected on the basis that fifty clasts could be extracted intact from one conglomerate bed; very indurated and very weathered outcrops were unsuitable.

The measured clasts ranged in size from 3.4 to 26.2 cm. Large pebbles ranged from 3% to 54% of individual samples, small cobbles from 44% to 86% and large cobbles from 0% to 16%. Elongate and discoidal clasts are often preferentially used in fabric studies of the A-axis and AB plane, respectively, (e.g., Schlee, 1957; Sengupta, 1966; Rust, 1972, 1975) as more spherical clasts are assumed to be more variable in their orientation. The use of all clast shapes is considered to increase variability and may even obscure the current direction (Potter and Pettijohn, 1963, p. 30). Clasts from the Keepit Conglomerate possess high sphericity values and plot towards the compact apex of the Sneed and Folk (1958) form triangle (Russell, 1977). This, together with the common difficulty of obtaining fifty clasts of all shapes from any one locality, prevented a restriction on clast shape being applied in this study. The clasts were extracted from the

Figure 1. Distribution of the Keepit Conglomerate in the northern part of the Tamworth Belt, N.S.W., showing fabric sample localities F1-3 to F14-39.

outcrop with the aid of a hammer and cold chisel. The position of the A-axis and the AB plane were marked upon the extracted clast, which was then repositioned in the outcrop face and the attitude of the A-axis and the AB plane measured with a Brunton compass. A small rigid plastic board was aligned coplanar with the AB plane to enable easier and more accurate measurement of the attitude. The time required for one operator to measure and record one sample of fifty clasts was usually in the order of four hours.

The data were plotted upon the lower hemisphere of an equal area (Schmidt) net. Correction for tectonic tilt was made by rotating the beds about the strike to the horizontal. Poles to the AB plane were contoured using the squared grid method of Stauffer (1966), while a Schmidegg contourer was used for contouring the A-axis diagrams (see Turner and Weiss, 1963, p. 60). The contoured diagrams are presented in Figure 2.

For each sample was calculated the direction ($\Theta$) and degree (L) of preferred orientation and the probability (p) that this preferred orientation was not due solely to chance, after the methods described by Curray (1956). This data is presented in Table 1.

The clast fabric paleocurrent directions given in Table 2 and used in Figure 3 were derived by relating the directions indicated by the maxima on the stereographic projections to the closest of the compass points N, NNE, NE, ENE, etc. Thus, a maximum indicating a bearing of, for example, 030° would be referred to NNE, while one of 035° would be referred to NE.

## Results

### The fluvial conglomerate fabrics

Samples F10-28, F11-29, F12-29 and F13-31 (Fig. 1) are from conglomerate beds interpreted as the deposits of braiding streams (Russell, 1977, 1979b). Each sample exhibits a very well developed concentration of poles to the AB plane (Fig. 2), indicating the presence of a well developed clast imbrication in these conglomerates. This fabric is typical of the AB plane imbrication exhibited by recent fluvial gravels, as discussed above, and can be considered to provide a reliable paleocurrent direction for the conglomerate beds from which these fabrics were recorded. Paleocurrents towards an eastnortheast direction are indicated for three of the samples, with a secondary maximum indicating for F12-29 northnortheast flow as well, and towards a northerly direction for F13-31. The vector means are in close agreement with these paleocurrent directions inferred from the stereographic projections (Table 2), the orientations being statistically very significant (Table 1).

The stereographic projections of the A-axes show variable distributions. F10-28 and F11-29 illustrate, respectively, a plunging unimodal fabric and a dipping girdle with the major maximum lying in the direction of dip of the girdle. Comparison with fluvial clast fabrics discussed above suggests these can be interpreted respectively as A-axes parallel to flow direction and plunging upcurrent, and an upstream dipping girdle with the dominant maximum parallel to flow direction. In both instances a reasonable agreement exists between the paleocurrent directions inferred from the A-axis plots and those from the AB plane plots. F13-31 exhibits a major maximum and two lesser oblique maxima. While a paleocurrent direction is not readily determined from this type of distribution, comparison with the AB plot shows the major maximum to be in close agreement with the flow direction indicated by the clast imbrication. F12-29 does not show a readily evident paleocurrent direction, and appears to consist of a southwest dipping girdle together with a unimodal concentration situated in a southerly position. Examination of the AB plane diagram shows two maxima, and it is possible that this sample has included two populations; one with A-axes forming a southwest dipping girdle with a major maximum parallel to flow direction and including the larger maximum of the AB plane plot, and the other with a unimodal A-axis distribution and related to the smaller AB maximum, indicating flow in a more northerly direction.

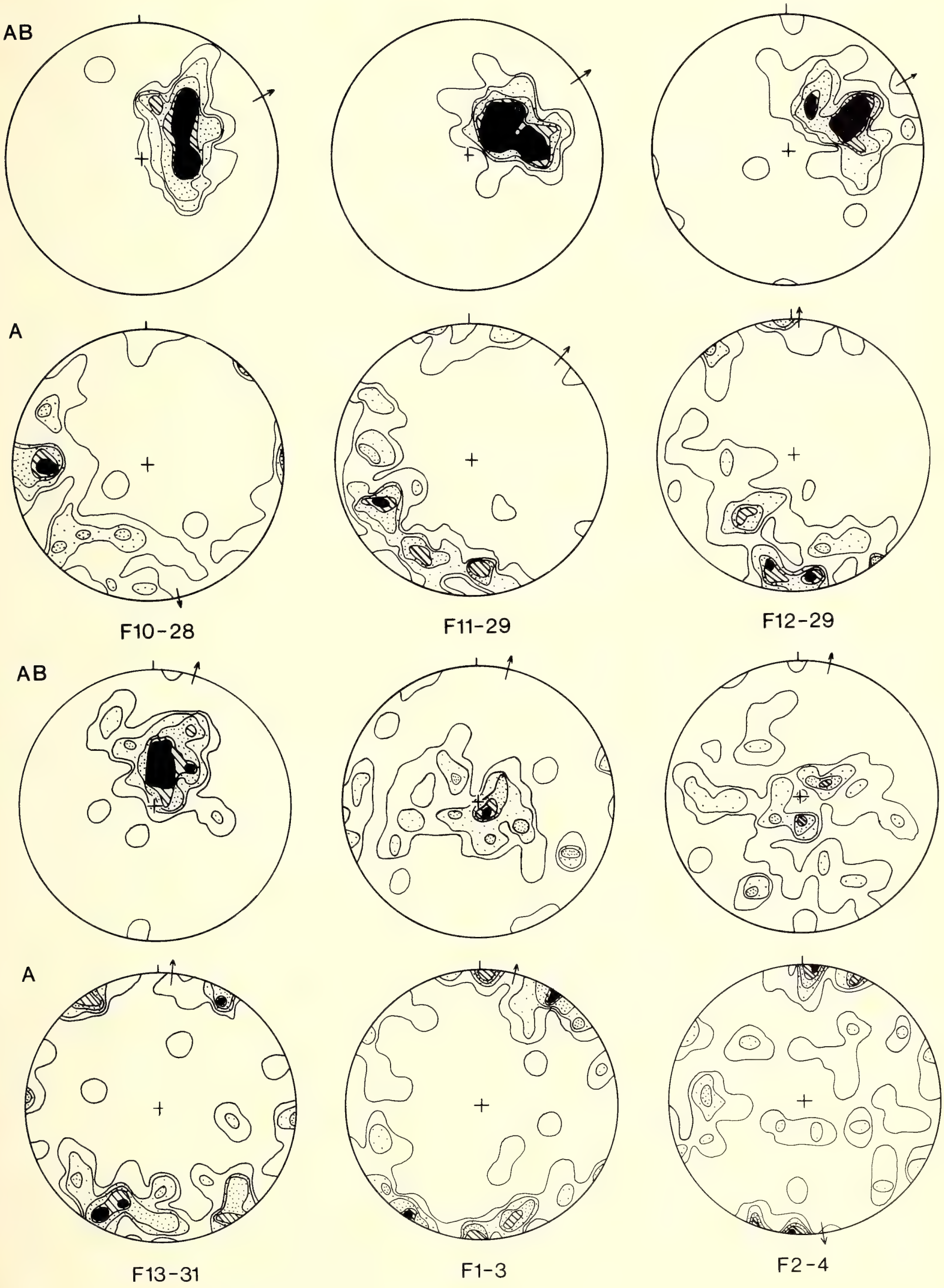
The best correlation of vector mean and apparent flow direction for the A-axis distributions is for sample F11-29. The vector mean for F13-31 is close in bearing to that for the AB planes, but those for F10-28 and F12-29 bear little relationship to the distribution or to the AB plane vector means.

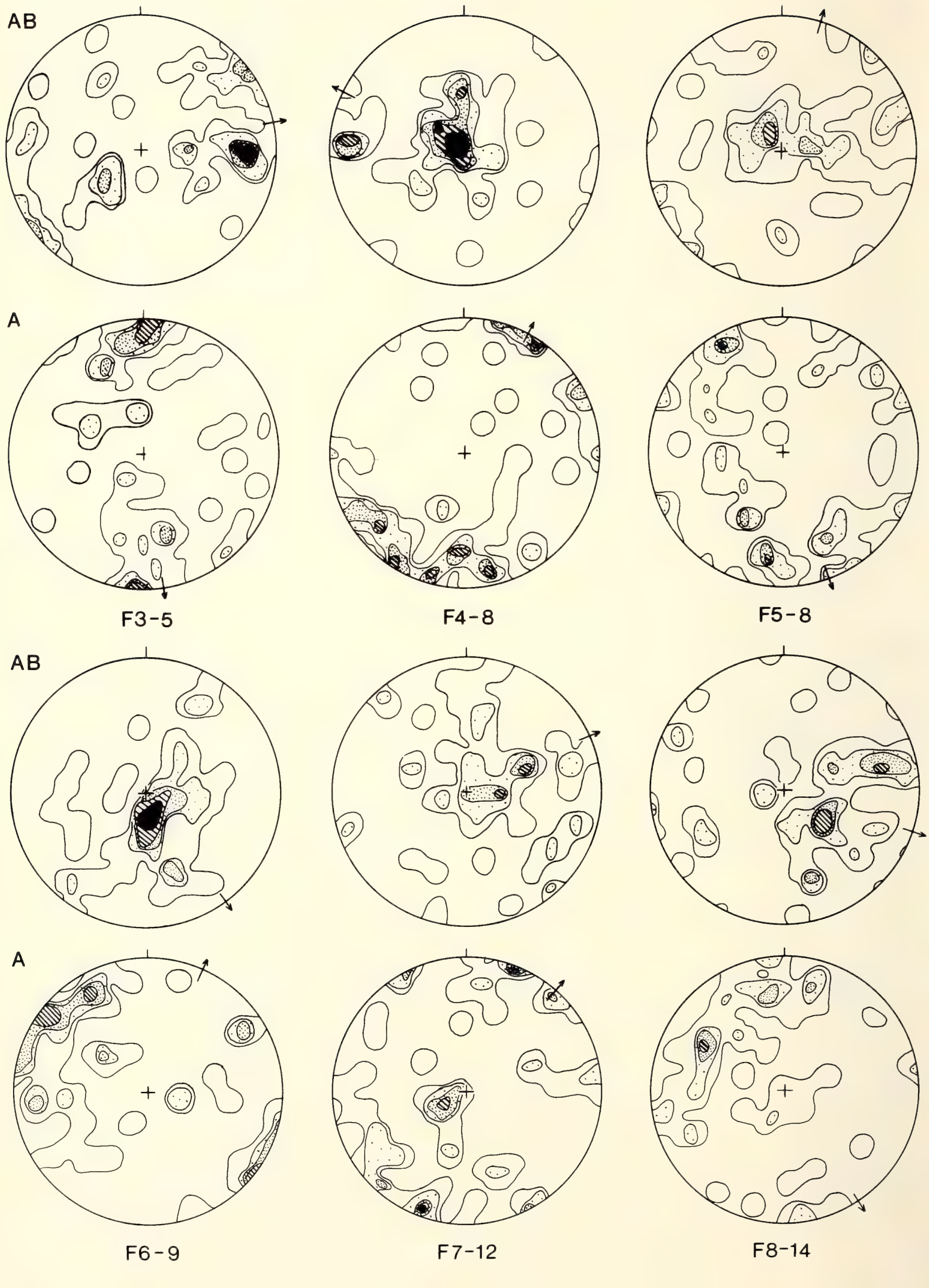
In conclusion, paleocurrents from the fabrics of the fluvial conglomerates are readily determined from the AB plane orientations. The A-axis fabrics of the fluvial conglomerates are more variable in the nature of their orientations, and paleocurrent directions from these distributions alone are in some instances less obvious, in others unobtainable. For all samples a close agreement exists between the A-axis orientations and the paleocurrent directions indicated by imbrication of the AB plane.

### The marine resedimented conglomerate fabrics

The marine resedimented conglomerate fabric samples are from massive (F2-4, F4-8, F6-9, F8-14, F14-39) and graded (F3-5, F5-8, F9-21) clast supported conglomerates and from matrix supported conglomerates (F1-3, F7-12).

The degree of imbrication exhibited by these conglomerates is variable. Imbrication is best developed in F4-8, F6-9, F9-21 and F14-39, each of which possesses a prominent maximum of poles to the AB plane (Fig. 2). Paleocurrent directions may confidently be determined from these conglomerates. The vector means for these samples are in close accord with the paleocurrent directions inferred from the fabric diagrams (Table 2), the orientations being statistically significant (Table 1). The remaining samples are characterised by more dispersed distributions of poles to the AB plane and lower concentration maxima. Fabric samples F1-3, F3-5, F8-14 possess weaker maxima, indicating the presence of less well developed imbrication within these conglomerates, which nevertheless may still be used to indicate paleocurrent directions.


AB
A
F10-28
F11-29
F12-29
AB
A
F13-31
F1-3
F2-4


AB
A
F3-5
F4-8
F5-8
AB
A
F6-9
F7-12
F8-14

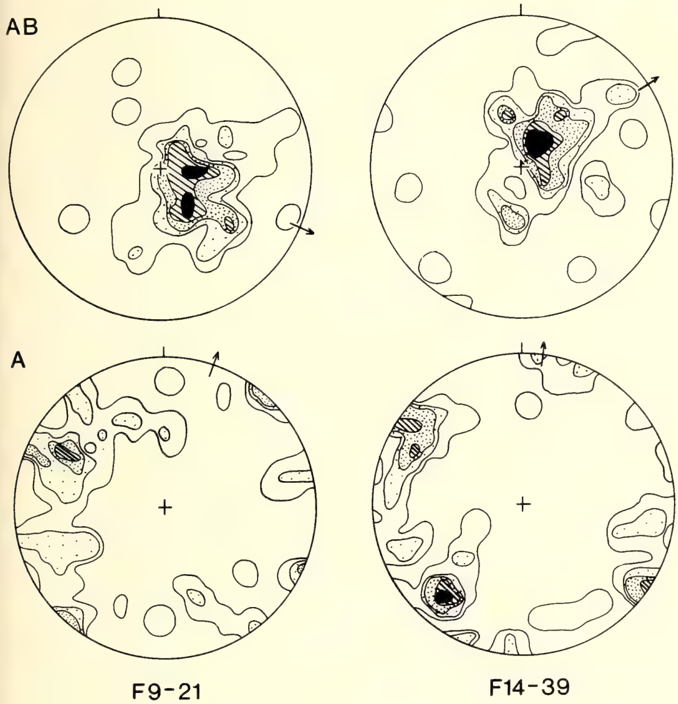



Figure 2.

Contoured stereographic projections of poles to the AB plane (AB) and A-axis orientation (A). Fabric samples F10-28, F11-29, F12-29, F13-31 are from fluvial conglomerates, the remainder are from marine resedimented conglomerates.

Contour intervals are 2, 4, 6, 8 and 10%. Tick marks indicate North and arrows represent the vector means (Table 1).

The relationship of the vector mean to the inferred paleocurrent directions is more variable, in response to the more dispersed nature of the distributions. Samples F2-4 and F7-12 are quite dispersed distributions, each with two relatively low strength maxima. An easterly paleocurrent direction is suggested for F7-12. However, due to the dispersed nature of the distributions and the presence of more than one low strength maximum, flow directions inferred from such fabric diagrams can only be considered tentative.

The A-axis fabrics for the marine resedimented conglomerates range from unimodal (e.g., F3-5, F6-9) to bimodal (e.g., F9-21, F14-39) distributions. The determination of paleocurrent directions from these distributions relies upon differentiation of maxima parallel and transverse to flow direction. A prominent maximum indicating plunging A-axes may reasonably be considered to represent clast A-axes aligned parallel to flow and plunging in an upcurrent direction (e.g., Walker, 1975a). Such a fabric is best illustrated by F9-21 and F14-39, indicating paleocurrents directed to the southeast and northeast, respectively. These distributions are both bimodal, possessing as well as an upstream plunging maximum a second maximum indicating subhorizontal A-axes oriented transverse to the inferred flow direction. Comparison with the AB plane fabric diagrams indicates a close agreement in inferred paleocurrent direction for these two samples. The remaining A-axis distributions do not readily provide paleocurrent data. Comparison with the appropriate AB plane fabrics shows the unimodal A-axis distributions to be either transverse (e.g., F1-3, F3-5) or parallel (e.g., F6-9, F8-14) to the inferred paleocurrent directions. The A-axis orientation for F5-8 is very dispersed, and neither readily indicates a paleocurrent direction nor relates to the AB plane distribution. The correlation of the A-axis vector mean with the probable paleocurrent directions is frequently poor, presumably due to the variable distribution of the A-axes. Those distributions which do show a close correlation of vector mean and the dominant maximum are primarily unimodal distributions (e.g., F1-3, F3-5, F4-8, F8-14). The relationship of vector mean to paleocurrent direction in these instances is dependent upon whether the unimodal distribution is parallel or transverse to flow direction. This in turn relies upon the presence of a prominent upstream plunging maximum, or reference to the AB plane fabric diagram.

To summarise, for marine resedimented conglomerates AB plane imbrication is the best paleocurrent indicator, although some conglomerates are not at all well imbricate, while A-axes being more variable in their orientation are less reliable as indicators of paleocurrent directions.

TABLE 1

TWO-DIMENSIONAL ORIENTATION DATA FOR FABRIC STUDY OF AB PLANES AND A-AXES

| Sample | AB Plane Vector Mean ($\theta°$)* | AB Plane Vector Magnitude (L%) | p** | A-axis Vector Mean ($\theta°$) | A-axis Vector Magnitude (L%) | p** |
|---|---|---|---|---|---|---|
| Fluvial Conglomerates | | | | | | |
| F10-28 | 063.88 | 78.52 | $0.4x10^{-13}$ | 168.80 | 20.23 | 0.13 |
| F11-29 | 056.92 | 84.71 | $0.26x10^{-15}$ | 041.83 | 24.58 | 0.049 |
| F12-29 | 059.57 | 81.17 | $0.49x10^{-14}$ | 003.97 | 33.16 | 0.0041 |
| F13-31 | 018.51 | 71.23 | $0.96x10^{-11}$ | 006.46 | 29.93 | 0.011 |
| Marine Resedimented Conglomerates | | | | | | |
| F1-3 | 014.56 | 23.82 | 0.058 | 015.60 | 21.11 | 0.11 |
| F2-4 | 013.09 | 20.66 | 0.12 | 172.33 | 3.26 | 0.95 |
| F3-5 | 078.36 | 14.02 | 0.37 | 171.03 | 41.53 | 0.00018 |
| F4-8 | 297.47 | 32.67 | 0.005 | 028.58 | 35.22 | 0.002 |
| F5-8 | 017.34 | 18.79 | 0.17 | 160.20 | 18.53 | 0.18 |
| F6-9 | 144.30 | 40.01 | 0.00034 | 024.09 | 38.03 | 0.00073 |
| F7-12 | 065.26 | 31.15 | 0.0078 | 041.34 | 29.84 | 0.012 |
| F8-14 | 108.08 | 39.56 | 0.0004 | 147.13 | 18.76 | 0.17 |
| F9-21 | 113.11 | 56.77 | $0.1x10^{-6}$ | 019.06 | 22.40 | 0.081 |
| F14-39 | 056.84 | 50.51 | $0.29x10^{-5}$ | 007.94 | 19.12 | 0.16 |

* $\Theta$ represents the current direction derived from the orientation of the AB plane, and not the dip direction of the AB plane ($\Theta \pm 180°$).

** probability that this degree of preferred orientation resulted fron random distribution.

### Relationship of vector mean to paleocurrent direction

The vector mean is considered a measure of the central tendency of a distribution and as such to indicate the preferred orientation direction (Curray, 1956). Paleocurrent directions may be inferred from the maximum (maxima) exhibited by a stereographic projection of clast fabric data. Ideally, if a distribution about a maximum representing, e.g., imbrication is symmetrical, the vector mean will represent the flow direction. If, however, as is often the case, there are also points dispersed irregularly about the maximum then the vector mean will deviate from a close association with the maximun in response to these more dispersed points. The amount of deviation from the maximum will depend in part upon the relative strength of the principal maximum and on the spread and degree of irregularity of the dispersed portion of the distribution. The vector mean in these instances, although still a measure of the central tendency of the distribution, will no longer possess a close relationship to the flow direction as indicated by the dominant maximum. The paleocurrent directions given in Table 2 and used in Fig. 3 are therefore based on the maxima exhibited by the stereographic projections of poles to the AB plane, rather than the vector means. These maxima reflect a preferred clast orientation, and as such are considered to provide a realistic indication of paleocurrent directions.

Vector means calculated for clast fabric distributions must therefore be interpreted or used as paleocurrent indicators with care, as in many instances this statistical direction of preferred orientation need have no close correlation with the probable flow direction as inferred from the maxima on a stereographic projection. In determining paleocurrent directions from clast fabrics consideration must be made of the distribution pattern exhibited by the stereographic projection.

### Relationship of clast fabric paleocurrents to other paleocurrent directions

Clast fabric paleocurrent directions compare favourably with paleocurrents derived from other sources. Walker (1977a) showed a very close correlation in paleocurrent direction between resedimented conglomerate clast fabrics and sole markings on turbidites interbedded with the conglomerates. Winn and Dott (1979) demonstrated a close agreement in paleocurrent directions between conglomerate fabrics and, where possible, flute casts on the same conglomerate beds. Rust (1975) has shown a close agreement between paleocurrent directions from gravel fabrics and the

TABLE 2

PALEOCURRENT DIRECTIONS INFERRED FROM STEREOGRAPHIC PROJECTIONS OF THE POLES TO THE AB PLANE

| Sample | Inferred Flow Direction | Vector Mean |
|---|---|---|
| Fluvial Conglomerates | | |
| F10-28 | ENE | 63.88° |
| F11-29 | ENE | 56.92° |
| F12-29 | ENE<br>NNE* | 59.57° |
| F13-31 | N | 18.51° |
| Marine Resedimented Conglomerates | | |
| F1-3 | SE | 14.56° |
| F2-4 | n.e. | 13.09° |
| F3-5 | E | 78.36° |
| F4-8 | NW | 297.47° |
| F5-8 | NNW | 17.34° |
| F6-9 | SSE | 144.30° |
| F7-12 | ENE<br>E* | 65.26° |
| F8-14 | SE<br>ENE* | 108.08° |
| F9-21 | ESE | 113.11° |
| F14-39 | NE | 56.48° |

n.e. flow direction not readily evident

* secondary mode

mean trend of channels and bars in braiding stream environments.

Keepit Conglomerate clast fabrics, with the exception of F4-8 and F5-8, indicate paleocurrent directions varying from southeast to east of north (Table 2, Fig. 3). Directional sedimentary structures are not commonly observed in the Keepit Conglomerate, and in only six of the measured sections from which clast fabrics were recorded could paleocurrents be obtained from sources other than the conglomerate fabrics. In these sections the sedimentary structures present were scarce and usually not in close association with the conglomerate from which the fabric was recorded. A comparison between the clast fabric paleocurrents and those derived from other sedimentary structures is given in Table 3.

The paleocurrent directions indicated by these structures in general agree with the directions inferred from the conglomerate fabrics, although differences up to 85° may be noted. The sole mark and cross stratification paleocurrent directions from the section in which F14-39 occurs are from Manser (1967). In this study it proved impossible to confirm these paleocurrent directions as the structures measured by Manser could not be located. The data has, however, been incorporated in this work. In the case of F8-14, where the paleocurrent directions are derived from observations made only two metres apart, this divergence reflects the differing flow directions of a channelised conglomerate and over-bank rippled sands typical of the submarine fan environment in which these sediments were deposited (Russell, 1977, 1979b). Paleocurrent variation of this magnitude between channel and interchannel deposits in submarine fan environments and sequences is to be expected (Nelson and Nilsen, 1974, p. 83; Walker, 1977b, p. 929).

Samples F4-8 and F5-8 display a southeasterly imbrication, opposite to all other samples. The reason for this is not clear. One possible explanation is the failure to recognise cross stratification in the conglomerate at the sample location, which would result in the plot of the poles to the AB plane indicating a current direction opposite to the actual direction (e.g., Liboriussen, 1975). However, Sengupta (1966) shows the A-axes on foresets to be parallel to the current direction, while the stereographic projections of Johansson (1963, Figs. 19, 20) and Liboriussen (1975, Fig. 4) show girdles dipping in a downcurrent direction, with strong maxima parallel to flow. The A-axis fabric for F4-8 is perpendicular to inferred flow direction, in

TABLE 3

COMPARISON OF CONGLOMERATE CLAST FABRIC PALEOCURRENT DIRECTIONS WITH PALEOCURRENT DIRECTIONS DERIVED FROM OTHER SEDIMENTARY STRUCTURES WITHIN THE SAME SECTION

| Fabric paleocurrent direction | | Other paleocurrent directions | | |
|---|---|---|---|---|
| Sample | AB Plane | Direction | Source | Number of readings |
| F1-3 | SE | 055° | Flute clasts | 3 |
| F3-5 | E | 137° | Flute clasts | 12 |
| | | 310°-130° | Tool casts | 3 |
| F8-14 | SE,ENE | 057° | Ripples | one exposure |
| F10-28 | ENE | 120° | Ripples | one exposure |
| F13-31 | N | 067° | Ripples | one exposure |
| F14-39 | NE | 130° | Sole marks | from Manser (1967) |
| | | 130° | Cross stratification | |

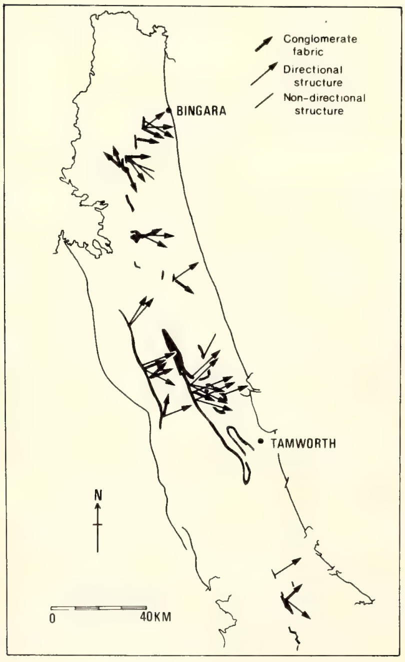



Figure 3. Paleocurrent directions for the Keepit Conglomerate (diagram based on Fig. 1). Directional structures - flute casts, cross stratification, ripples, scours; non-directional structures - tool casts, apparent A-axis orientations.

contrast to the A-axis orientation of clasts deposited on foreset beds. Subsequent field checking failed to establish the presence of cross stratification.

The clast fabric paleocurrent data for the Keepit Conglomerate indicate current flow in an essentially easterly direction. A depositional basin with a source area to the west and an easterly sloping paleoslope is supported by this paleocurrent pattern. On a basin scale, this pattern is consistent with paleocurrent data obtained for the Keepit Conglomerate from other directional sedimentary structures (this study, Fig. 3) and the limited paleocurrent data for the Keepit Conglomerate available from other sources. White (1966) infers easterly flowing paleocurrents from three conglomerate fabrics from the north of the Tamworth Belt, while Manser (1967) reports southeasterly flowing paleocurrents from limited sole marks and cross stratification in the southernmost outcrops of the Keepit Conglomerate. This paleocurrent pattern for the Keepit Conglomerate is also consistent with the existing limited paleocurrent data for the Lower Devonian to Carboniferous Tamworth Belt sequence (Crook, 1964; McKelvey, 1966; White, 1966; Manser, 1967; McKelvey and White, 1968; Moore and Roberts, 1976). A westerly source terrain with sediment dispersal in an easterly direction is also indicated by the thickness, clast size and lithology trends for the Keepit Conglomerate, and the distribution of terrestrial and marine domains of sedimentation (Russell, 1977, 1979b).

## CONCLUSIONS

Clast fabric data from terrestrial and marine conglomerates of the Late Devonian Keepit Conglomerate provide useful and valuable paleocurrent information in a unit lacking in directional sedimentary structures.

Conglomerate clast imbrication as indicated by stereographic projections of poles to the AB plane, provides in most instances a reliable indication of paleocurrent direction for both the fluvial and the marine resedimented conglomerates of the Keepit

Conglomerate. A-axis fabrics are more variable in the nature of their distribution and are therefore of more limited use in paleocurrent studies. Clast A-axis fabrics may indicate a paleocurrent direction if a prominent upcurrent plunging A parallel to flow maximum can be identified. Paleocurrents derived from such A-axis distribution agree well with paleocurrent directions derived from imbrication of the AB plane. AB plane fabrics are thus considered more useful in their ease of interpretation and reliability in clast fabric paleocurrent studies of conglomerates.

Clast fabric studies of the Keepit Conglomerate yield paleocurrent directions which in general agree with those obtained from other sedimentary structures in the Keepit Conglomerate and by previous workers on the Devonian-Carboniferous Tamworth Belt sequence. Paleocurrent data, together with lateral variation in marine and terrestrial lithologies, thickness and grain size variation all suggest for the Keepit Conglomerate a source located to the west with current flow down an easterly sloping paleoslope.

ACKNOWLEDGEMENTS

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## APPENDIX

| Fabric Sample | Horizon (metres above base of section) | Section Locality |
|---|---|---|
| F1-3 | 15 m | GR34352935 Inverell 1:250,000 |
| F2-4 | 4 m | GR34002895 Inverell 1:250,000 |
| F3-5 | 13 m | GR33572795 Manilla 1:250,000 |
| F4-8 | 9 m | GR33452743 Manilla 1:250,000 |
| F5-8 | 68 m | GR33452743 Manilla 1:250,000 |
| F6-9 | 8 m | GR33652740 Manilla 1:250,000 |
| F7-12 | 35 m | GR34172414 Manilla 1:250,000 |
| F8-14 | 18 m | GR35862255 Manilla 1:250,000 |
| F9-21 | 18 m | GR36611727 Manilla 1:250,000 |
| F10-28 | 251 m | GR34661783 Manilla 1:250,000 |
| F11-29 | 150 m | GR34751764 Manilla 1:250,000 |
| F12-29 | 91 m | GR34751764 Manilla 1:250,000 |
| F13-31 | 112 m | GR35311597 Tamworth 1:250,000 |
| F14-39 | 8 m | GR41030742 Tamworth 1:250,000 |

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# The Geology of an Area Near Cudgegong, New South Wales

JOHN W. PEMBERTON*

ABSTRACT. In the area immediately southeast of Cudgegong, the Cudgegong Fault separates probable Ordovician and Silurian rocks in the west from an Early Devonian sequence in the east. The Aarons Pass Granite, of possible Kanimblan (Late Carboniferous) age, outcrops in the southwest part of the area. In the south, Permian conglomerates unconformably overlie the older rocks.

The oldest rocks are the ?Sofala Volcanics, a sequence of metamorphosed pyroxene andesites with lenticular chert and calc-silicate lenses of possible Ordovician age. They are overlain by the Silurian Willow Glen Formation (new name), a sequence of shallow water litharenites, limestones and rhyodacitic tuffs. The Toolamanang Volcanics (new name) consist of rhyodacitic lavas and breccias, volcarenites and lutites, and conformably overlie the Willow Glen Formation. The above sequence bears a strong lithological resemblance to that established by Packham (1968) in the Sofala area. Suggested correlations are the ?Sofala Volcanics with the Sofala Volcanics; the Willow Glen Formation with the Tanwarra Shale; and the Toolamanang Volcanics with the Bells Creek Volcanics. The intrusion of the Aarons Pass Granite has thermally metamorphosed the southern outcrops of the ?Ordovician and Silurian rocks. Adjacent to the granite, this metamorphism is represented by rocks of both hornblende-hornfels and albite-epidote-hornfels facies.

The Early Devonian rocks are a shallow water sequence deposited on the Capertee Geanticline. The lowest unit, the Roxburgh Formation (new name), consists of a sequence of quartzarenites, lutites, conglomerates and sublitharenites. The unit is overlain by the dacitic Riversdale Volcanics. This is in turn disconformably overlain by the limestones and litharenites of the Carwell Creek Beds. The Early Devonian strata are folded in a broad south-plunging anticline and syncline with tight, small-scale folding in the cores, and faulting on the limbs.

## INTRODUCTION

The village of Cudgegong lies within the central-western slopes district of New South Wales (Fig. 1). It is located approximately 260 km by road NW of Sydney at a longitude of 149°50'E and latitude of 032°49'S. It lies 35 km to the SE of Mudgee, at the junction of the Cudgegong River with a tributary, Cudgegong Creek and it is 46 km by road NW of Capertee.

One of the dominant geomorphic features of the Mudgee - Cudgegong - Kandos region is the sub-Permian peneplain of altitude about 800 m above sea level. In the area this is largely eroded although, on the southern boundary, a thin (up to 5 m) veneer of Permian sediments nonconformably overlies the Aarons Pass Granite and unconformably overlies both the ?Ordovician-Silurian and Devonian sequences. The terrain slopes gently down to the north as a series of undulating hills and valleys.


Fig. 1. Locality map of the Mudgee - Cudgegong region.

## PREVIOUS GEOLOGICAL INVESTIGATIONS

Sussmilch (1934) studied the Devonian strata immediately west of Kandos (20 km east of Cudgegong). He recognised a sequence of several thousands of metres of Late Devonian quartzites with thin claystone and limestone horizons, folded into a series of anticlines and synclines with common small scale faulting.

Game (1934) mapped a wide tract of Silurian and Devonian strata south of Mudgee. At Cudgegong, his Silurian sequence was dominantly volcanic with basal altered tuffs and lavas overlain by a thick limestone horizon and subsequently by a thick belt of "felspathic tuffs". He gave a Late Devonian age to the sequence of quartzites (with thin horizons of limestone, claystone, tuffs and grits) which were considered to form the core of a south-plunging anticline, the western limb of which outcrops a few kilometres east of Cudgegong.

Hill (1969) mapped the area immediately southeast of Cudgegong. The structure and stratigraphy recognised in this paper differ markedly from that of Hill, so detailed discussion is not

* communicated by A.J. Wright

appropriate. Stratigraphic terminology is modified where necessary.

Packham (1969, p. 108-109) has interpreted "thinly bedded sandstones and shales" in the Cudgegong sequence as equivalent to the Chesleigh Formation.

Powis (1975) mapped an area near Millsville, 24 km NW of Cudgegong. His basal unit was a series of Silurian "rhyodacitic flows and breccias with discontinuous conglomerate and rare limestone horizons". Powis regarded these volcanics as a northerly extension of the sequence outcropping near Cudgegong township.

GEOLOGICAL SETTING

In the Mudgee - Cudgegong district, a belt of Ordovician and Silurian volcanics and sediments separates two narrow fault-bounded belts of Devonian fossiliferous sediments (Wright, 1966). These include representatives of both the Hill End Trough and Capertee Geanticline sequences.

In the Sofala - Hill End region there are strata ranging in age from Middle Ordovician to possibly Middle Devonian (Packham, 1968). The Ordovician Sofala Volcanics consist of 2000 m of clastic and pyroclastic detritus with a small percentage of lavas. The Silurian Tanwarra Shale (80 m of shale, conglomerate and limestone) rests with a slight break on the Sofala Volcanics. The rhyolitic lavas and tuffs of the Bells Creek Volcanics overlie the Tanwarra Shale. To this point the Cudgegong and Sofala sequences are similar, and indicate Hill End Trough and possibly older deposits.

The Sofala rocks are conformably overlain by further Silurian sediments and Devonian volcanics and sediments completing the marine deposition in the Hill End Trough. The equivalent part of the Cudgegong sequence was deposited on the Capertee Geanticline.

STRATIGRAPHY

The effect of the Cudgegong Fault makes it possible to consider the sequence of basement rocks in two categories - Devonian and older (Fig. 2).

Early Palaeozoic Stratigraphy

The sequence of ?Ordovician to Silurian age can be subdivided into three units, two of which are given new names herein. The basal unit, the ?Sofala Volcanics, consists of metamorphosed andesites with chert and calc-silicate hornfels lenses. This unit is overlain by the litharenites, limestones and rhyodacitic tuffs of the Silurian Willow Glen Formation. It is, in turn, conformably overlain by the Toolamanang Volcanics, a sequence of rhyodacitic lavas and breccias, volcarenites and lutites.

?Sofala Volcanics

A sequence of metamorphosed andesitic volcanics with interbedded lenses of chert and calc-silicate hornfels outcrops in the southern portion of the area. This sequence is tentatively correlated with the Sofala Volcanics (see Discussion). The present mineral assemblages are altered from the original andesitic composition. These assemblages have been produced by two periods of metamorphism, the first of which was a low grade regional metamorphism. Superimposed on this is a contact metamorphism associated with the emplacement of the Aarons Pass Granite producing a narrow aureole of hornblende-hornfels facies.

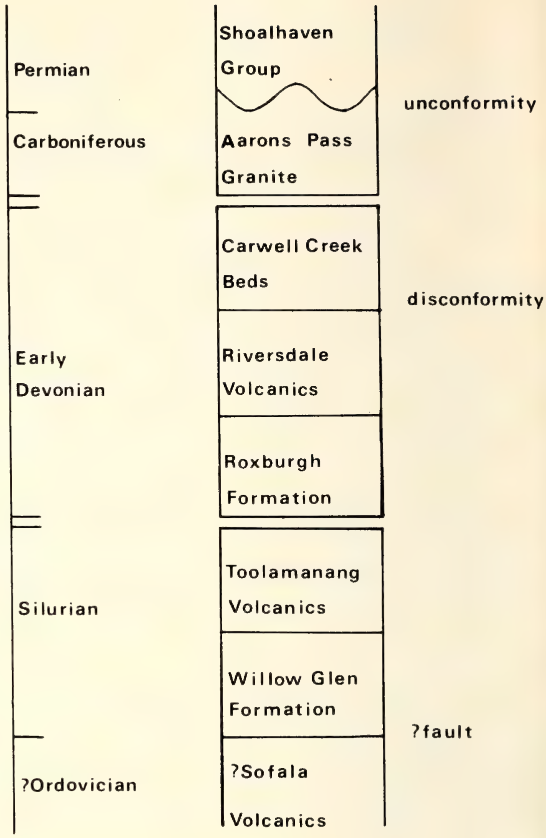



Fig. 2. Stratigraphy of the Cudgegong district.

The unit outcrops in a narrow north-south trending belt approximately 2 km east of Aarons Pass (Fig. 3). Boundaries with the surrounding rock types are obscured by poor outcrop, but the eastern boundary seems to be faulted, whereas the western boundary with the overlying Silurian Willow Glen Formation is uncertain. The Volcanics are unconformably overlain by Permian conglomerates in the south and are intruded by the Aarons Pass Granite in the southwest.

A representative section across the ?Sofala Volcanics is taken from GR 765550 636200 to GR 763950 6362200. The section exposes fine- to coarse-grained andesites with no discernible sequence. Dips are absent and mappable horizons are discontinuous along strike. The andesites are

well-jointed with apparently random orientations.

Disseminated sulphides are present within many of the rocks. Relatively massive deposits have been found at the Cheshire Copper Mine (GR 765200 6362700) and the Milfor prospect (GR 765000 6360950). The defunct mine is located within altered andesites with the assemblage tremolite-epidote-albite-chlorite. The major sulphides are pyrite, chalcopyrite, sphalerite, galena and arsenopyrite; minor sulphides are tetrahedrite, pyrrhotite, bornite, chalcocite, covellite and cubanite; native copper also has been recorded (all after Hill, 1969).

Mineralogy

The ?Sofala Volcanics have undergone regional metamorphism to greenschist facies. The metamorphism has produced the assemblage: tremolite/actinolite + albite $\pm$ epidote $\pm$ carbonate $\pm$ biotite $\pm$ chlorite in most rocks. In the vicinity of the Aarons Pass Granite the volcanics have been thermally metamorphosed to hornblende-hornfels facies. The resultant assemblages are dominated by diopside, tremolite/actinolite and andesine ($An_{35-40}$). Generally the assemblages are silica-deficient, especially so close to the granite contact where green spinel and olivine form part of the assemblage (rock specimen R6567). In this aureole, calc-silicate hornfelses are also present as small lenses within the volcanics. The presence of the calcium silicates tremolite/actinolite, epidote and diopside, as well as calcite, and grossular/andradite garnet emphasises the calcium-rich nature of all the rock types. Free quartz is mostly lacking although chert fragments are present within many of the rocks.

Textural features

The ?Sofala Volcanics can be divided into four rock groups based on their texture and mineralogy. Rocks with a porphyritic texture are most common, with non-porphyritic rocks outcropping in thin layers with a north-south trend. The calc-silicate hornfelses outcrop irregularly as small lenticular patches, and a massive chert horizon trends approximately north-south.

In hand-specimen the porphyritic rocks are dark green, massive, holocrystalline, mesocratic and medium- to coarse-grained. Phenocrysts are subhedral to euhedral with plagioclase and pseudomorphs after pyroxene common. The groundmass is fine-grained with a dark green colour.

In thin-section these rocks are blastoporphyritic with relict phenocrysts and amygdules set in a fine intergranular groundmass. The phenocrysts, up to 4 mm in length, now consist of principally tremolite/actinolite ($\alpha = \beta$ = colourless to pale green, $\gamma$ = light to dark green) and colourless epidote. Contact metamorphism of the tremolite/actinolite pseudomorphs gives rise to diopside at higher grades. The amygdules, up to 2 mm in maximum dimension, are filled by poorly twinned albite anhedra together with fine tremolite/actinolite needles up to 0.5 mm in length; these are associated with calcite and brown biotite anhedra. The groundmass consists of decussate aggregates of albite ($An_8$), tremolite/actinolite and epidote. In rocks less affected by contact metamorphism the groundmass phases display intergranular textures.

The nonporphyritic rocks differ from their coarser equivalents in being even-grained, dark green in colour with a homogeneous appearance. Relict phenocrysts and amygdules, up to 2 mm in maximum dimension, are present. The amygdules contain the same phases as the coarser equivalents whereas the phenocrysts are now mainly tremolite/actinolite and albite-oligoclase ($An_{10}$ with Carlsbad and albite twinning). The groundmass of these rocks is similar to that of the coarser equivalents, however the amount of albite ($An_{8-10}$) is greater relative to the other phases, epidote and tremolite/actinolite. Original intergranular textures are locally preserved, yet are replaced by hornfelsic ones close to the granite.

Calc-silicate hornfels and rocks outcropping near the granite contact exhibit a medium to coarse (up to 3 mm in maximum dimension), even-grained texture. The andesites in the aureole are mineralogically similar to those outside (yet diopside commonly replaces some of the tremolite/actinolite anhedra) whereas the calc-silicate hornfels contains tremolite/actinolite, diopside, calcite, and colourless grossular/andradite garnet.

A black chert horizon forms a discontinuous bed within the volcanic sequence. All samples are fine-grained and highly fractured with fine quartz veins infilling these fractures. Hill (1969) recorded Radiolaria from the chert but none has been observed by the author.

Metamorphism

With the exception of calc-silicate and chert horizons, the rocks outside the granite aureole exhibit moderately altered volcanic textures whereas within the aureole these textures are replaced by a hornfelsic one. Mineral assemblages of rocks outside the aureole are dominated by tremolite/actinolite and albite whereas those close to the granite contain diopside-tremolite/actinolite-andesine (-epidote).

Pyroxene andesite, consisting of calcic plagioclase ($An_{40-60}$) and lime-bearing clinopyroxene, could alter to compositions similar to those above through the breakdown, at low grades, of calcic plagioclase to albite and epidote and of clinopyroxene to tremolite/actinolite and calcite. At higher temperatures the latter reaction is reversed, thus explaining the presence of diopside (replacing tremolite/actinolite) and andesine in rocks closer to the granite.

The isochemical character of the thermal metamorphism is indicated by the overall similarity in bulk mineral composition of both regionally and contact metamorphosed volcanics. However, it seems that prior to contact metamorphism, alteration of the volcanics took place during regional metamorphism and this alteration involved the transfer of chemical components under low temperature hydrous conditions, as suggested by (Vallance, 1967).

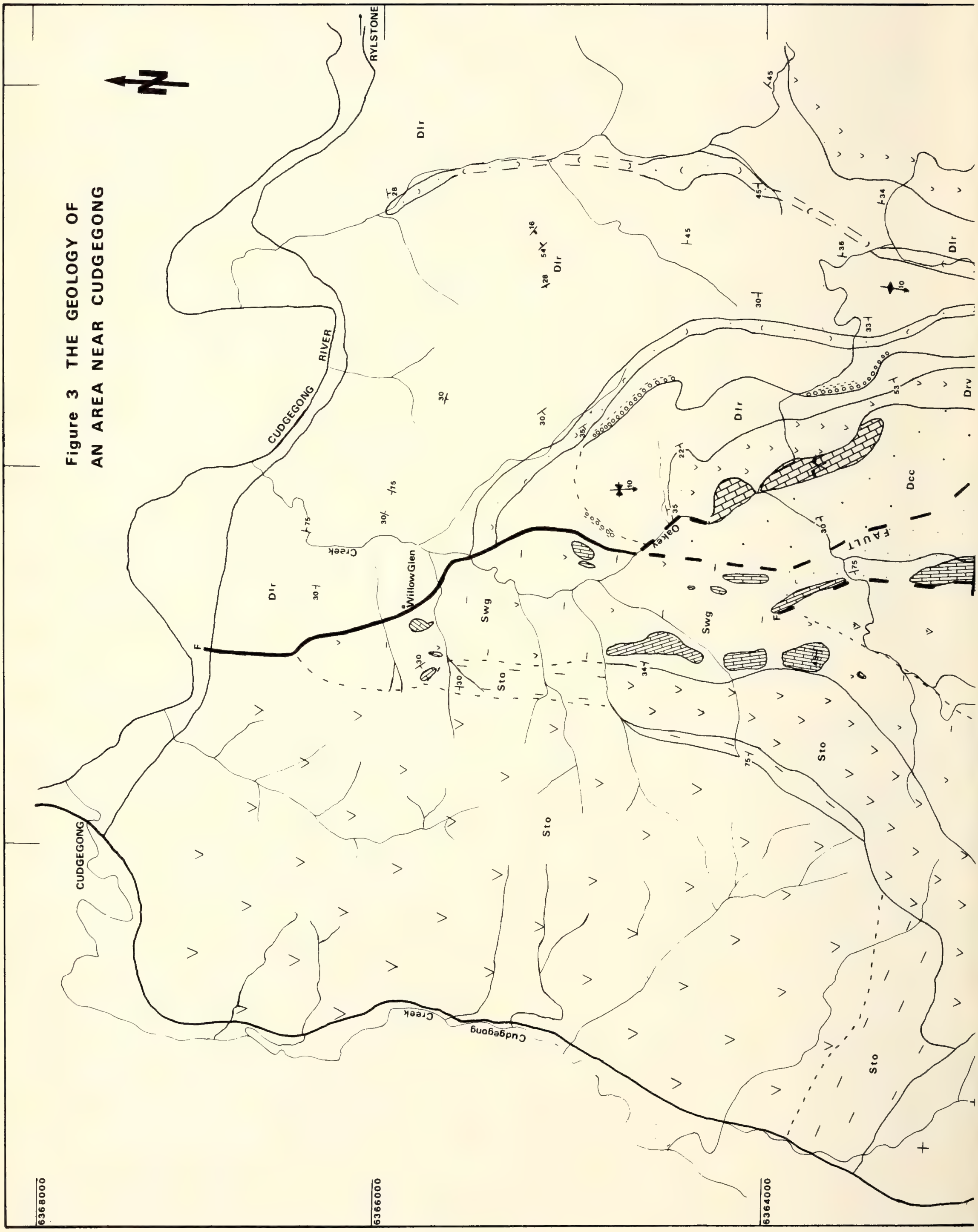
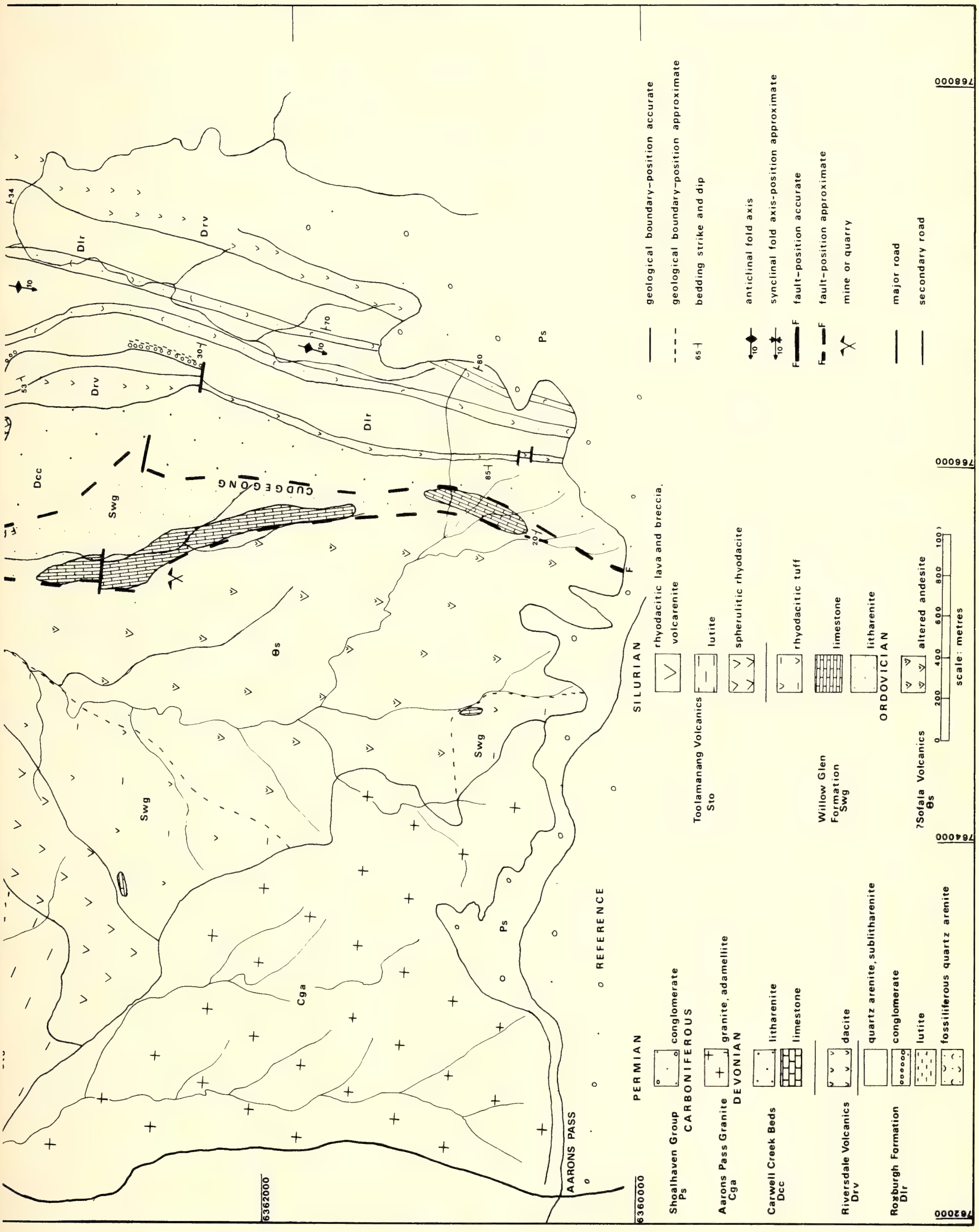



Fig. 3. The geology of an area near Cudgegong


CUDGEGONG
AARONS PASS
REFERENCE
PERMIAN
Shoalhaven Group Ps
conglomerate
CARBONIFEROUS
Aarons Pass Granite Cga
granite, adamellite
DEVONIAN
Carwell Creek Beds Dcc
litharenite
limestone
Riversdale Volcanics Drv
dacite
Roxburgh Formation Dlr
quartz arenite, sublitharenite
conglomerate
lutite
fossiliferous quartz arenite
SILURIAN
Toolamanang Volcanics Sto
rhyodacitic lava and breccia, volcarenite
lutite
spherulitic rhyodacite
Willow Glen Formation Swg
rhyodacitic tuff
limestone
litharenite
ORDOVICIAN
?Sofala Volcanics Θs
altered andesite
0 200 400 600 800 1000
scale: metres
geological boundary-position accurate
geological boundary-position approximate
bedding strike and dip
anticlinal fold axis
synclinal fold axis-position approximate
fault-position accurate
fault-position approximate
mine or quarry
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secondary road
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Ps
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Cga

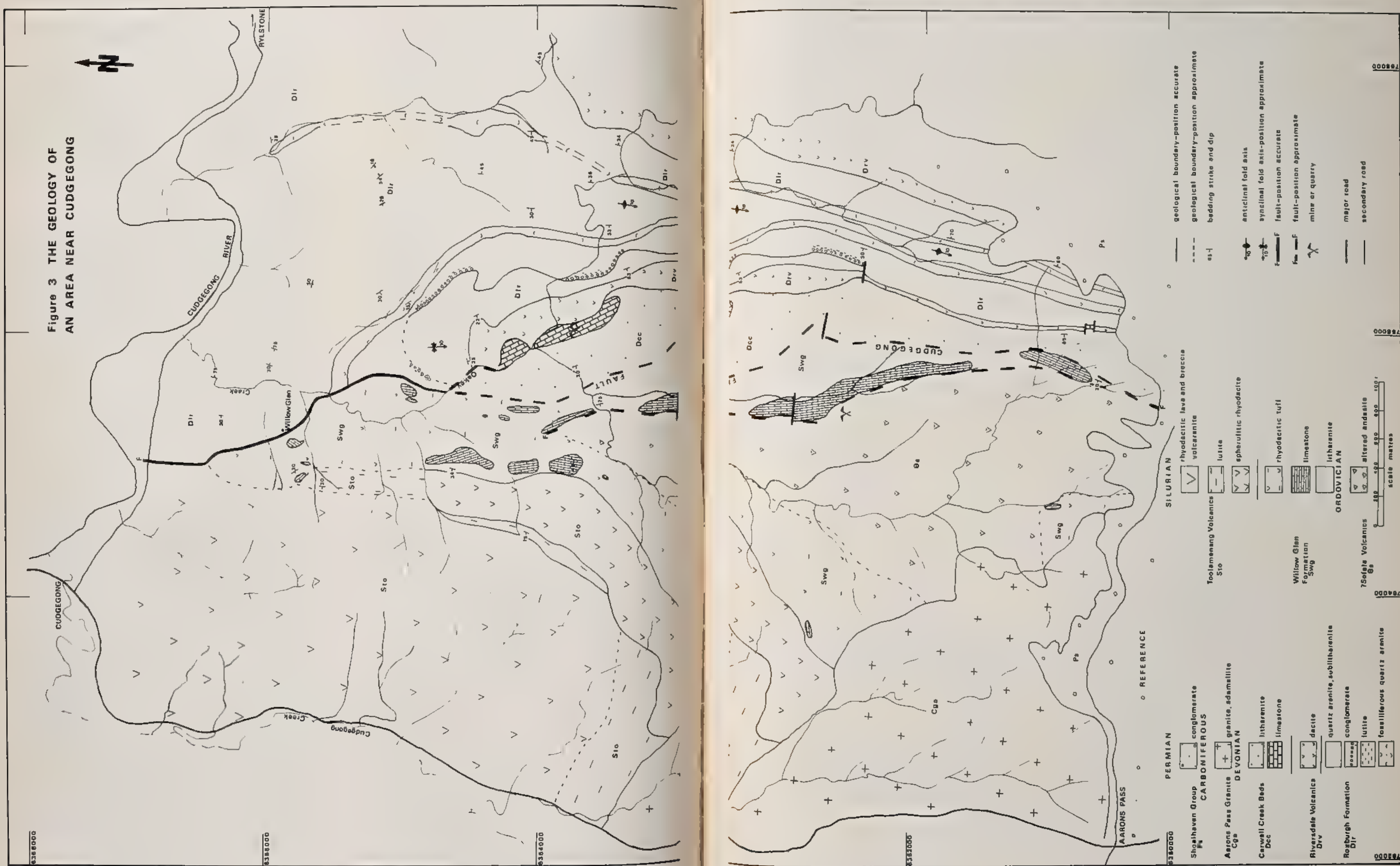


Fig. 3. The geology of an area near Cudgegong

Willow Glen Formation (new name)

The formation derives its name from the Willow Glen property. The Willow Glen Formation outcrops in a westerly dipping belt up to 700 m wide and over a length of about 6.5 km. The belt splits (near GR 764950 6364050) into two narrow belts outcropping to the east and west of the ?Sofala Volcanics against which they are possibly faulted; this bifurcation might alternatively indicate an underlying anticlinal structure. Both belts thin rapidly to the south where they are unconformably overlain by Permian conglomerates. The western belt is intruded in the southwest by the Aarons Pass Granite. The resulting contact metamorphism has altered the strata to a low grade hornfels. The Willow Glen Formation is conformably overlain to the west by the Toolamanang Volcanics. Limestones of the former unit grade through limestone breccias to the shales of the latter unit in the north whereas in the south the boundary is sharp. The limestone outcrops are lenticular and their lateral equivalents, rhyodacitic tuffs, grade upwards into well-bedded shales of the Toolamanang Volcanics. The eastern boundary is the Cudgegong Fault (Game, 1934) which brings the Willow Glen Formation into contact with the Devonian rocks.

A stratigraphic section for the Willow Glen Formation (Fig. 4) combines the maximum thicknesses of individual members, giving an overall thickness of 900 m; the thickness in any single section is of the order of 600 m.

The lowest exposure in the Willow Glen Formation is a coarse, dark grey, massive litharenite best exposed near GR 765800 6363000. In thin-section, small well-sorted sub-angular quartz grains (up to 50% of the rock), oligoclase ($An_{16}$ to $An_{20}$) grains, green biotite and cherty rock fragments, up to 1 mm across, are set in a coarse silica cement, which may constitute up to 50% of the rock.

The litharenite is overlain by the lower limestone bed. In the north this unit is a pale, grey, white to dark-grey biomicrite. Most samples are highly fractured and strongly cleaved in directions from 350$^{\circ}$ to 010$^{\circ}$. Silty interbeds towards the top of the bed dip at 30$^{\circ}$ toward 250$^{\circ}$. The limestone is sparsely fossiliferous with a fauna of poorly preserved corals and brachiopods. Small rounded chert pebbles and mica flakes are dispersed throughout this member. Along strike to the south the limestone thickens to a very coarse-grained, massive, dark grey, unfossiliferous marble with the equivalent of the northern outcrop limited to a thin horizon, to 1 m thick, at the top of the bed.

A rhyodacitic tuff horizon overlies the lower limestone bed with a sharp contact (GR 765000 6364400). The rock is massive, very fine-grained, grey-black with a highly fractured and jointed appearance. It consists of angular quartz, albite, and brown biotite grains, up to 0.1 mm long, in a fine siliceous groundmass. Near the top of the member fine shaley interbed dip at 40$^{\circ}$ to 50$^{\circ}$ towards 260$^{\circ}$.

It is overlain by the upper limestone bed. This member outcrops as a series of lenticular pods with lateral changes to the well-bedded rhyodacitic tuff. The basal and upper parts of the limestone are well-bedded and poorly fossiliferous with common small chert pebbles. Towards the middle, the size and number of the pebbles increases rapidly together with an increase in the amount of silty interbeds. Brachiopod tests, mainly disarticulated *Kirkidium*, become more abundant. Geopetal structures produced by these tests indicate the sequence is right way up (i.e. the Willow Glen Formation underlies the Toolamanang Volcanics).

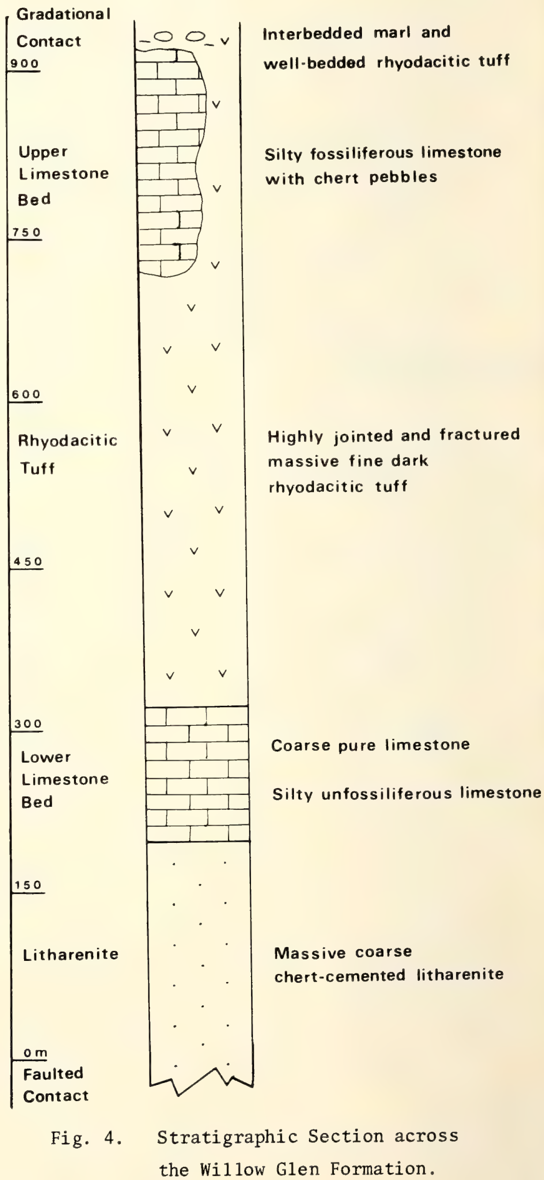


Fig. 4. Stratigraphic Section across the Willow Glen Formation.

Along strike to the south, the two uppermost members lie within the contact aureole of the Aarons Pass Granite. The resultant hornfelses consist of marbles, fine dark hornfelses and spotted hornfelses.

The marbles are massive, white to pink in colour, very coarse-grained and somewhat soft and friable. Outlines of recrystallised brachiopod tests are prominent.

The fine dark hornfels is grey to black in colour and massive. Microscopically the assemblage quartz - plagioclase (albite to oligoclase) - brown biotite-muscovite-pyrite forms an even-grained hornfelsic texture with an average grain-size of 0.5 mm.

The spotted hornfels is fine-grained, dark grey and well-bedded with rounded black porphyroblasts to 4 mm diameter. The porphyroblasts are accumulations of fine muscovite flakes with thin rims of brown biotite. They pseudomorph an earlier-formed mineral, perhaps cordierite. The matrix contains quartz-plagioclase (albite)-brown biotite anhedra with a hornfelsic texture.

Fauna and age

The lower limestone bed is poorly fossiliferous with fauna restricted to crinoid ossicles and favositid and heliolitid corals. The upper limestone bed is richly fossiliferous yet diversity of species is low. The faunal list from the upper limestone bed was compiled by Wright (pers. comm.) of fossils from GR 764700 6364000.

*Kirkidium* sp. indet., favositid and heliolitid corals, crinoid stems and stromatoporoids.

The presence of the brachiopod *Kirkidium* indicates a Silurian age for the Willow Glen Formation. No conodonts have been found within either of the two limestone beds.

Toolamanang Volcanics (new name)

The name is derived from the Parish of Toolamanang. In the area studied, rhyodacite flows and breccias, lutites and volcarenites outcrop over a width of 2.3 km. Aerial photograph interpretation and Offenberg et al. (1971) suggest that this unit is continuous over some distance to the west of Cudgegong Creek and thus the true thickness of this unit is not known but must exceed 3 km, while the known extent along strike is at least 20 km.

A representative section across the Toolamanang Volcanics is taken from GR 764500 6363700 to GR 762400 6364700. It gives a thickness of about 1200 m for the Toolamanang Volcanics in the area to the east of Cudgegong Creek.

The rhyodacites, rhyodacitic breccias and volcarenites are massive and highly jointed. They conformably overlie well-bedded westerly-dipping strata of the Willow Glen Formation. Westerly-dipping shaley horizons in the Volcanics confirm that this dip continues through the area to the west of the Willow Glen Formation.

The two basal units of the sequence, the lower spherulitic rhyodacite and the overlying lutite horizon, can be recognised over most of the strike length of the Toolamanang Volcanics in the area mapped. They are overlain by rhyodacite flows and breccias, and volcarenites. None of these latter rock types outcrop continuously over any distance.

The spherulitic rhyodacite outcrops as a prominent ridge up to 500 m wide yet its width decreases abruptly in the north and south. The contacts with both underlying and overlying strata are sharp. The rocks vary from black to white in colour; are massive, have a vitreous lustre and are highly fractured. In thin-section angular phenocrysts (up to 1 mm across) of quartz and oligoclase occur with spherulites to 0.5 mm diameter and biotite ($\alpha$ = light brown, $\beta$ = $\gamma$ = dark green) anhedra to 0.2 mm across in a very fine siliceous groundmass.

In the south, lutites (up to 50 m thick) overlie the spherulitic rhyodacite with a sharp contact, whereas in the north the spherulitic rhyodacite lenses out and a thicker lutite sequence (up to 200 m) rests directly on the Willow Glen Formation. The lutites outcrop as well-bedded, fissile, unfossiliferous strata varying in colours of brown, grey and purple. Bedding is consistently dipping at about 30 to $40^{o}$ towards $270^{o}$.

The fine-grained rhyodacite is dark grey to black, massive, glassy and well jointed. In thin-section small angular quartz and oligoclase grains, up to 0.1 mm across, are set in a very fine groundmass of quartz, albite and brown biotite.

The volcarenites are grey to black, massive and coarse grained. In thin-section poorly sorted, angular to rounded, broken plagioclase (andesine $An_{40}$ to oligioclase $An_{12}$) grains, up to 2 mm across, angular quartz grains and cherty rock fragments, to 1 mm across, are set in a matrix of fine albite ($An_{10}$) laths with quartz and green biotite anhedra.

The rhyodacitic breccias consist of large angular elongate clasts, up to 2 cm long, of fine-grained rhyodacite in a matrix of the typical volcarenite. The clasts are poorly-sorted, randomly oriented and may constitute from 5% to 50% of the rock.

Metamorphism

The presence of fine biotite and chlorite flakes, and the albitisation and sericitisation of feldspars within most rocks indicates that they have suffered the imprint of low grade regional metamorphism. The southern extension of the Toolamanang Volcanics has been affected by low grade thermal metamorphism associated with the granite emplacement. Within the volcarenites the plagioclase grains are albitised ($An_{10}$) and actinolitic amphiboule ($\alpha$ = $\beta$ = pale green, $\gamma$ = dark green) is commonly present in the matrix. Metamorphism of lutite members produces assemblages typified by quartz - albite ($An_8$) - green biotite - muscovite. These hornfelses are mineralogically similar to those developed within pelitic sediments of the Willow Glen Formation but differ texturally in that they lack a spotted appearance.

Devonian Stratigraphy

Within the area three Devonian units can be recognised. The basal unit, the Roxburgh Formation, consists of quartzarenites, conglomerates, lutites, and sublitharenites of Early Devonian age. It is disconformably overlain by the dacitic Riversdale Volcanics which is, in turn, sharply overlain by the Carwell Creek Beds - a sequence of limestones and litharenites. Faunal data and lithological similarities are insufficient to correlate these formations with any described elsewhere in New South Wales (Packham, 1969).

Roxburgh Formation (new name)

The formation derives its name from the County of Roxburgh. The sediments of the Roxburgh Formation outcrop in a south-plunging syncline and anticline; the former is bounded in the northwest by the Cudgegong Fault. The unit is overlain by the Riversdale Volcanics in both the east and west, and unconformably by Permian conglomerates in the south. The base of this Formation is not exposed in this area.

A stratigraphic section for the Roxburgh Formation is given in Figure 5. The section is taken along Oakey Creek between GR 766700 6364000 and GR 765900 6364150. The constituent units are continuous along strike varying in width yet with little lithological variation. The overall thickness of the representative section is about 550 m.

Lowermost in the exposed section, a thick sequence of immature quartzarenites is interbedded with thin horizons of micaceous, arenaceous lutite. The arenites are grey-white to red in colour and are massively bedded with units up to a few metres thick. Cross-bedding and ripple marks are developed within the finer horizons. The fine interbeds may be up to tens of centimetres thick but are usually thinly-bedded. Well-preserved brachiopods and crinoid debris are found within some interbeds. The arenites grade upwards into an excellent marker horizon of coarse quartzarenite with abundant angular, poorly fossiliferous limestone clasts up to 3 cm in length and moderately well-preserved brachiopod shells. Abundant brachiopod shells are commonly tightly packed within softer arenaceous interbeds in the arenites. This horizon grades up into a thick series of well-bedded coarse to fine quartzarenites. The beds are poorly fossiliferous with cross-bedding in the fine and coarse interbeds common.

The arenite sequence contains a thin, conformable acid volcanic body along Oakey Creek near GR 766050 6364050. It appears most likely to be a sill up to 70 m long, probably associated with small-scale faulting which is common in the northern portion of the unit.

An excellent marker sequence, up to 200 m thick, of lutite - conglomerate - coarse quartzarenite with limestone clasts - sublitharenite overlies the sill. The lutite is a fine, massive, unfossiliferous cream to white unit up to 50 m thick. It has a sharp contact with the overlying conglomerate horizon which contains well rounded and sorted acid volcanic pebbles, up to 2 cm diameter, with thin hematite rims in a quartzarenite matrix which may constitute up to 20% of the rock. The pebbles consist of angular quartz and poorly-twinned, sericitised plagioclase phenocrysts, up to 2 mm long, in a fine quartz, sericite and carbonate groundmass. The thickness of the conglomerate varies between 2 m and 5 m. The overlying quartzarenites are coarse-grained, massively bedded with sparse angular limestone clasts. They grade upward into a unit of fine, well bedded red to grey sub-litharenites which vary markedly in thickness, reaching 50 m and thinning rapidly along strike. These are overlain by coarser arenites which are thickly bedded with thin, silty interbeds common. These massively bedded arenites contain abundant angular limestone clasts and rounded chert pebbles up to 5 cm in diameter. The limestone is poorly fossiliferous, with crinoid debris and poorly preserved corals present.

The top of the Roxburgh Formation is marked by a fine massive quartzarenite. It has a sharp contact with the overlying, more ruggedly outcropping dacites of the Riversdale Volcanics.

Fauna and age

A number of fossil localities have been found within the interbedded quartzarenites of the Roxburgh Formation. The most important of these are discussed below. The following faunal lists have been compiled by Wright (pers. comm.).

Locality 1 (GR 766300 6363900); The fauna at this locality includes: *Iridistrophia* sp. indet. *Delthyris* sp. indet., cf. *Pterinopecten*, favositid and auloporid corals.

Locality 2 (GR 765600 6365300); Fauna includes: *Isorthis* sp. indet., *Howellella* sp. indet., cf. *Pterinopecten*, dalmanellid gen. indet., stropheodontid gen. indet.

Locality 3 (GR 766050 6365900); cf. *Atrypa* sp. indet., *Gypidula* sp. indet., favositid corals, crinoid stems, *Iridistrophia* sp. indet., rhynchonellids.

The presence of the brachiopod *Iridistrophia* together with *Delthyris* and *Howellella* suggests an Early Devonian age for the Roxburgh Formation.

Riversdale Volcanics (Offenberg et al., 1971)

This name was first proposed by Wright (1966) for outcrops to the east and north of this area and to date this unit has not been formalised. The Riversdale Volcanics outcrop on the limbs of a south-plunging anticline. As a result, the dacites of this unit form two narrow strips which outcrop continuously for 3.5 km along strike. The western strip varies markedly in thickness reaching a maximum of 200 m in the north, whereas to the south it is only 30 m thick. The top of the eastern strip has not been mapped but the strip is considerably thicker than 200 m. The unit overlies the Roxburgh Formation and is unconformably overlain by Permian conglomerates in the south. In the west, the dacite is abruptly overlain by the basal limestone member of the Carwell Creek Beds. In the north, this western strip abuts against the

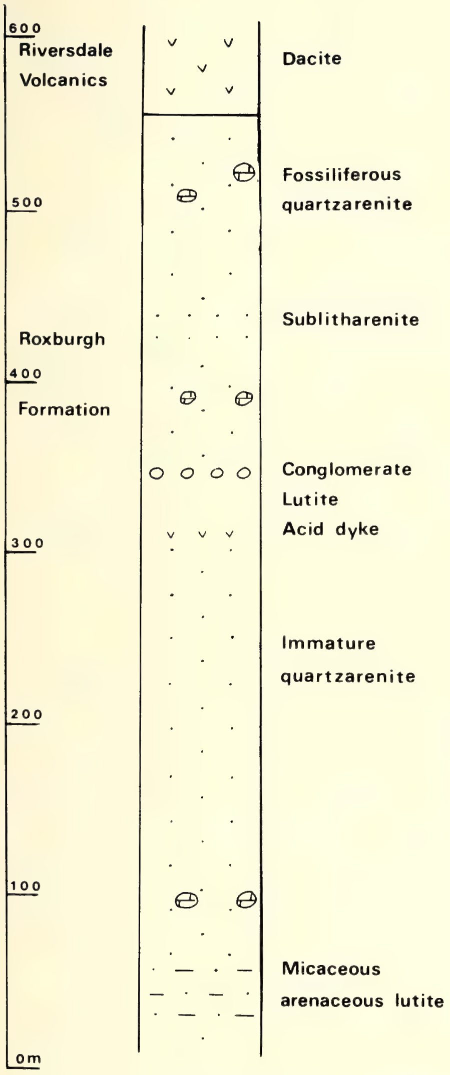


Fig. 5. Stratigraphic section across the Roxburgh Formation.

Cudgegong Fault. Along its strike this strip is cut by a number of east-west trending, small-scale faults.

Although there is little lithological variation along strike, a distinct sequence has been noted across the unit. At its base, the formation is fine-grained, white to green in colour, massive and highly fractured. Small angular quartz phenocrysts are set in a fine white groundmass. This grades into a purple massive very hard rock of slightly coarser grain size. Towards the top of the unit the purple volcanics are highly weathered and fractured. Large angular quartz and feldspar anhedra, up to 5 mm long, form in a grey white to pink flow banded groundmass.

In thin-section, the typical dacite is composed of angular quartz and sericitised, poorly-twinned sodic plagioclase phenocrysts up to 2 mm long in a fine, flow banded, silica-rich groundmass.

Carwell Creek Beds (Offenberg et al., 1971)

This unit outcrops as a north-south trending wedge of limestone and litharenite with a strike length of 3.5 km. Immediately above the sharp contact (which has a relief of several metres), clasts of the Riversdale Volcanics up to 50 cm in diameter are locally present. The basal limestone bed, up to 100 m thick, is a grey white, finely bedded intrasparite with rounded to elongate limestone clasts up to 5 cm in diameter. The limestone is poorly fossiliferous with rare stromatoporoids, corals and crinoid ossicles present. It grades upwards to a pink-white, massive, coarse-grained and highly fractured sparite. It is overlain by, and passes laterally into, a repetitive sequence of fine to coarse litharenites which are traceable along the outcrop of the Beds. Each fine to coarse sequence is about 150 m thick and up to 3 such sequences can be mapped across the unit. The sequences are dominated by massive, poorly sorted and poorly fossiliferous arenite which consist of approximately equal amounts (up to 70% of the rock) of angular quartz grains and cherty rock fragments, up to 2 mm across, in a fine silica and sericite cement constituting up to 30% of the rock.

The litharenites are unconformably overlain by Permian conglomerates in the south and disconformably overlie the Riversdale Volcanics in the east. They are bounded to the west by the Cudgegong Fault.

Permian Stratigraphy

The Permian strata at Cudgegong were deposited near the western margin of the Sydney Basin. The strata are part of the Permian Shoalhaven Group and were known locally as the Capertee Group consisting of "massive, fine to coarse conglomerates with subordinate breccias, grits, sandstones, siltstones, and slates" (McElroy, 1962).

Only the basal member of the Shoalhaven Group, the Megalong Conglomerate, is present at Cudgegong as a relatively thin (less than 15 m thick) veneer of "massive cobble conglomerate" (McElroy, 1962).

Shoalhaven Group (Megalong Conglomerate)

These Permian conglomerates are well exposed at the rim of an elevated plateau to the south of the Cudgegong River near Cudgegong. The conglomerates, up to 5 m thick, outcrop poorly and provide a flat-lying area used as pasture lands.

The nonconformable contact with the Aaron's Pass Granite is best seen at GR 762500 6360500 and GR 763300 6361100, where weathered granite is sharply overlain by the conglomerate. Here, angular to subrounded quartz and K-feldspar grains (up to 4 cm across), and smaller rhyodacitic clasts (up to 3 cm in maximum dimension) are set in a grey-brown, coarse arenite matrix. Where overlying the ?Sofala Volcanics, there is apparently

no material derived from the Volcanics within the overlying conglomerates. These contain rounded quartz pebbles and rhyodacitic clasts of smaller size (up to 2 cm across) than those in conglomerates overlying the granite. They are sparsely distributed in a yellow, white or red arenaceous matrix. Similarly the contact with the Devonian strata is obscured by poor outcrop. White to yellow coarse arenaceous matrix contains poorly sorted, large, angular cobbles of Devonian quartzarenites up to 1 m across. The size of the cobbles varies markedly within outcrops.

AARONS PASS GRANITE

The Aarons Pass Granite is a massive equidimensional stock, approximately 10 km in diameter. This body is discordant with the country rocks and was emplaced by the Late Carboniferous Kanimblan Orogeny (Powell et al., 1976).

The northeastern portion of the Aarons Pass Granite intrudes ?Ordovician and Silurian strata in the southwest of the area. It is nonconformably overlain by Permian strata to the south. The percentage of K-feldspar to total feldspar varies from 52% to 76%. This indicates that the Aarons Pass Granite belongs in the adamellite to granite range (Williams et al., 1955). The felsic nature of the rocks is shown by the high modal percentage of quartz (39% to 56%) and total feldspar (40% to 57%) and low content of biotite (0.4% to 2.9%). Both aplite and pegmatite occur as minor phases.

The rocks are pink to grey-white, massive, holocrystalline, leucocratic and coarse-grained. In thin-section, the rock is even-grained with a hypidiomorphic-granular texture. It consists of quartz anhedra (to 2 mm across), K-feldspar subhedra (to 2 mm long) displaying both film and bleb microperthite, plagioclase (oligoclase, $An_{15}$) subhedra (to 2 mm long), and biotite subhedra (to 1.5 mm long) with a pleochroic scheme $\alpha$ = light green brown to $\beta = \gamma$ = dark brown. Coarse myrmekitic intergrowths are present and small zircon inclusions are common in the biotite grains.

The contact with the Toolamanang Volcanics in the north is marked by a steep scarp where the granite abuts the resistant spherulitic rhyodacite member of the Volcanics. The rhyodacite is highly fractured there with thin aplite veins present along the fracture planes. The contact with the Milfor Volcanics is marked by the presence of large (up to 1 m across), altered andesitic xenoliths in the granite near GR 764000 6361400. The hornfelsic equivalents of the Willow Glen Limestone sequence outcrop poorly and, as a consequence, the contact with the granite is obscured. Aplite forms as thin, yet persistent veins and dykes within the hornfelses. Sparse, randomly oriented, subvertical aplite dykes intrude the xenoliths and the volcanic and granite masses. Dykes vary consistently between 1 and 1.5 m thick, although a few dykes on the eastern granite margin may reach 5 m thick, and may outcrop continuously over hundreds of metres. A pegmatitic phase outcrops as small irregular patches throughout the granite. Within the patches, large, up to 5 cm long, euhedral quartz and K-feldspar crystals develop in a granite "groundmass".

STRUCTURE

The Cudgegong Fault (Game, 1934) separates Ordovician and Silurian units in the west from an Early Devonian sequence in the east. It appears to be a strike fault over most of its length, yet to both the north and south of the area it cuts across the strike of most units. The fault is emphasised by a band of ironstone several metres wide discontinuously outcropping along its length.

?Sofala Volcanics

One interpretation of the outcrop pattern of this unit is that it represents a north-plunging anticlinal structure. However a lack of macroscopic bedding and the random nature of the joint orientations fail to support this interpretation. Another possibility is that the outcrop represents a faulted wedge of andesite although, as noted earlier, outcrop is poor on the western margin and hence the nature of this contact is speculative. The unit is bounded on the eastern margin by a fault along which several discontinuous aplitic dykes have been emplaced. The fault is also emphasised by the abrupt termination of a darker-coloured acidic dyke (composed of quartz, oligoclase and biotite) which is traceable across most of the formation. There is also a probable fault breccia developed in an adjacent Silurian limestone.

Willow Glen Formation

Bedding recorded from the area generally dips at about $30^{\circ}$ to $40^{\circ}$ towards about $250^{\circ}$ to $260^{\circ}$.

Toolamanang Volcanics

The outcrop pattern of the spherulitic rhyodacite and the westerly dips of the overlying lutite unit suggest a synclinal structure for the Formation. As bedding cannot be seen in the rhyodacite, the only support for this suggestion lies in the joint pattern; joints in the northern outcrops trend along $010^{\circ}$ whereas those closer to the granite trend along $330^{\circ}$.

Devonian Strata

The three Devonian units outcrop in a syncline-anticline structure. The western limb of the former is cut off by the Cudgegong Fault. The syncline plunges at $10^{\circ}$ toward $160^{\circ}$. The anticline crops out to the east, plunges at $10^{\circ}$ toward $175^{\circ}$; and is approximately symmetrical.

DISCUSSION

Regional Correlation

?Sofala Volcanics and Sofala Volcanics

Packham (1968) described the stratigraphic sequence for the Sofala area, 40 km to the south of Cudgegong. The basal unit, the Sofala Volcanics, consists of "approximately 7000 feet of..... clastic and pyroclastic detritus with a small percentage of lavas" (Packham, 1968, p. 112). Pickett (1978) suggested an age of mid-Gisbornian to Early Eastonian for conodonts, corals and algae from an agglomerate, and graptolites from meta-

sediments, in the Sofala Volcanics.

A comparison between the ?Sofala Volcanics and Sofala Volcanics (Table 1) shows an obvious similarity between the lavas of the two sequences, especially between the andesites at Cudgegong and the upper portion of the Sofala Volcanics. It may be that the exposed portion of the ?Sofala Volcanics correlates with the upper portion of Sofala Volcanics. This is consistent with the greater thickness of the Sofala Volcanics.

limestone, grading into shales and rhyodacitic bands of the Toolamanang Volcanics. The type section of the Tanwarra Shale is 40 km to the south of Cudgegong, and lithological differences of the observed magnitude caused by lateral facies changes could be expected over such a distance.

Toolamanang Volcanics, Bells Creek Volcanics and Mullions Range Volcanics

Rhyolitic lavas and tuffs of the Bells Creek

TABLE 1

COMPARISON OF THE SOFALA VOLCANICS (AFTER PACKHAM, 1968 AND BARRON, 1975) AND THE ?SOFALA VOLCANICS (NEW DATA)

| | ?Sofala Volcanics | Sofala Volcanics |
|---|---|---|
| Dominant rock type | altered, probably originally, pyroxene andesite. | pyroxene andesite |
| Other rock types | chert, calc-silicate lenses | medium to fine andesitic sandstones, chert, limestone lenses |
| Primary igneous phases | diopside | augite, hornblende |
| Other phases | tremolite/actinolite, epidote, albite, carbonate, biotite, chlorite, quartz | quartz, chlorite, carbonate, albite, epidote, tremolite, talc. |
| Metamorphic grade | greenschist facies | greenschist facies |
| Volcanic textures preserved | phenocrysts and amygdules in an intergranular groundmass | Phenocrysts and less common amygdules in an intergranular to trachytic groundmass. |

Willow Glen Formation and Tanwarra Shale

Packham (1968, p. 115) considered that the Silurian Tanwarra Shale rests "with a slight break" on the Sofala Volcanics. At Sofala, in the type section, the Tanwarra Shale is up to 80 m thick with a basal conglomerate member up to 14 m thick. It is composed of material derived from pyroxene andesites of the Sofala Volcanics. The conglomerate is overlain by a fossiliferous, impure limestone and, in turn, by shales. The presence of acid tuff layers indicates a conformable boundary with the overlying Bells Creek Volcanics.

A tentative correlation between the Tanwarra Shale and Willow Glen Formation is proposed. Both sequences overlie (originally) pyroxene andesites, have faunas indicative of a Silurian age, and are overlain by acid volcanic rocks. However, a number of differences have been noted between the sequences. Firstly, the Willow Glen Formation sequence is up to 900 m thick compared with the 80 m thickness of the Tanwarra Shale. Secondly the lithological differences are marked. The Tanwarra Shale exhibits a type sequence of basal conglomerate - limestone - shale. The Willow Glen Formation, at Cudgegong, consists, of basal litharenite - limestone - pyroclastic -

Volcanics conformably overlie the Tanwarra Shale at Sofala (Packham, 1968). The volcanics, associated with slates, cherts and shales, vary markedly in thickness along strike but are traceable over large distances confined to the western side of the Wiagdon Thrust. According to Packham (1968, p. 155), "The Bells Creek Volcanics may then be correlated approximately with the Mullions Range volcanics; both are probably Middle Silurian". The Mullions Range Volcanics outcrop in the Euchareena district as a series of dacitic and rhyolitic lavas, and as part of the Molong Geanticline sequence.

Comparison of the above mentioned volcanic units is represented by Table 2. It would appear that the units have many similar features. However, glass shards are present within the southern formations. Spherulites are present within the basal rhyodacite of the Toolamanang Volcanics. They may form by the devitrification of glassy material.

Summary of the Regional Correlation

Lithological correlations have been made between the ?Sofala Volcanics and Sofala Volcanics and between the Toolamanang Volcanics and Bells

TABLE 2

COMPARISON OF THE BELLS CREEK VOLCANICS (PACKHAM, 1968), MULLIONS RANGE VOLCANICS (PACKHAM, 1968) AND TOOLAMANANG VOLCANICS (NEW DATA).

| | TOOLAMANANG VOLCANICS | BELLS CREEK VOLCANICS | MULLIONS RANGE VOLCANICS |
|---|---|---|---|
| Dominant Rock Types | rhyodacitic lavas and breccias, volcarenites | rhyolitic lavas and tuffs | dacitic and rhyolitic lavas and breccias |
| Lava Phenocrysts | quartz, plagioclase (albite to oligoclase) | quartz, orthoclase albite | orthoclase albite, quartz |
| Glassy Material | spherulites | glass shards in tuff | glass shards in tuff |
| Breccias | rhyodacitic fragments | rhyolitic fragments | dacitic fragments |
| Lava Groundmass | quartz, albite | quartz, feldspar, biotite, epidote | quartz, feldspar biotite, epidote |
| Clastic Fragments | only in volcarenites | none | no data |
| Associated Rock Types | shales | slates, cherty shales | Sandstones, tuffs |

Creek Volcanics. The correlation between the Willow Glen Formation and Tanwarra Shale is considered tenuous. The two sequences are represented by Figure 6. Each stratigraphic column is drawn showing the relative thickness of the individual units.

The Sofala sequence (Sofala Volcanics - Tanwarra Shale - Bells Creek Volcanics) ranges from Middle Ordovician to Middle Silurian. The contact between the lower two units is largely obscured by overthrust faulting while the upper

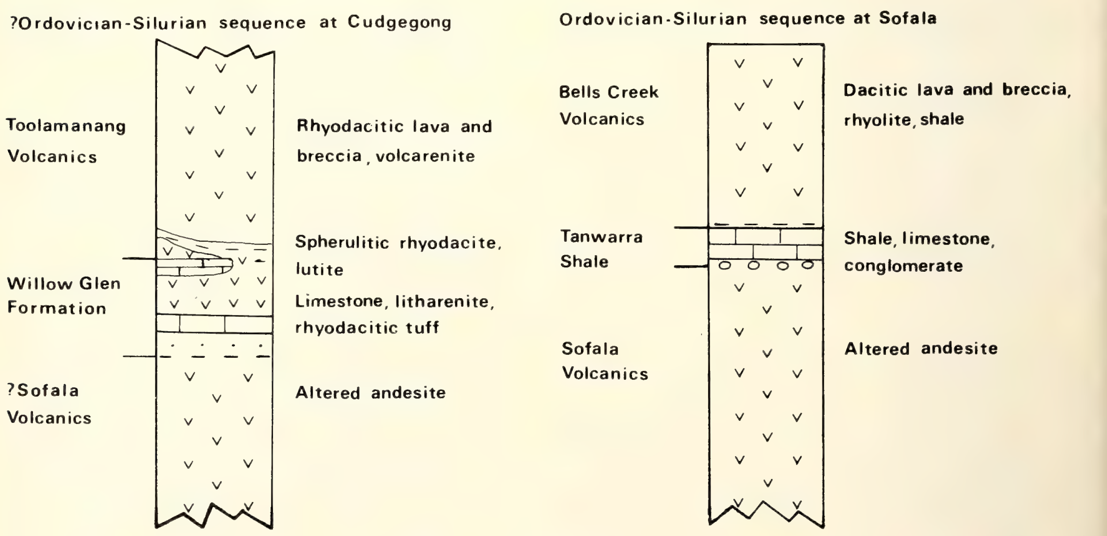


Fig. 6. Comparison of the Ordovician - Silurian sequences at Cudgegong and Sofala.

contact is considered conformable by Packham (1968).

At Cudgegong, the sequence ?Sofala Volcanics - Willow Glen Formation - Toolamanang Volcanics has been established. The contact between the lower two units is obscured by poor outcrop whereas the upper contact is considered conformable. The fauna of the Willow Glen Formation suggests a Silurian age. The sequence is given an age of ?Ordovician - Silurian based on its correlation with the Sofala sequence.

The Cudgegong Sequence related to the Development of the Hill End Trough

The Molong Geanticline was characterised by andesitic island arc volcanism during the Ordovician. The Late Ordovician Benambran Orogeny caused extensive metamorphism and uplift to the geanticline particularly on its eastern margin (Matson, 1975). Gilfillan (1976) considered the Sofala Volcanics was part of the eastern margin of the Molong Geanticline prior to its "splitting" due to the Middle Silurian Quidongan Orogeny. The Sofala Volcanics were relocated toward the eastern margin of the newly formed Hill End Trough (Scheibner, 1973).

The depositional environment of the Tanwarra Shale and Bells Creek Volcanics remains a problem. However, recognition of the Sofala sequence (Sofala Volcanics - Tanwarra Shale - Bells Creek Volcanics) equivalents at Cudgegong strongly suggests that if the Hill End Trough formed by the rifting of the eastern part of the Molong Geanticline, then this occurred either before the deposition of the Tanwarra Shale or after (or during) the accumulation of the Bells Creek - Toolamanang (-Mullions Range) acid volcanic suite. Consideration of the unconformable contact between Sofala Volcanics and Tanwarra Shale and the conformable contact between the Tanwarra Shale and Bells Creek Volcanics strengthens the former suggestion. Alternatively, the widespread nature of the above threefold sequence might be taken to negate any concept of such rifting.

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# Pitfalls in Hand Spectroscopy*

HENRY LAU AND KEN STEELE

ABSTRACT. Laboratory staff wearing absorptive lenses using a hand spectroscope can wrongly recognise the presence of a haemoglobin pigment. We are reporting one such case from our laboratory. Subsequently the absorptive properties of a group of commonly used absorptive lenses were analysed.

It was brought to our attention that during the performance of a Schumm's test (Varley 1967) using a Hartridge Reversion Spectroscope a member of our staff recognised an alpha and beta band of a haemoglobin pigment which he thought may have been an albumin haemochromogen. However other laboratory staff disagreed with his findings as no one else was able to see the bands described by that member of our staff. The specimen was scanned on a Unicam S.P. 800 and no absorptive bands were detected.

After sometime we concluded that the bands seen by that person were real, when his spectacles were placed in the specimen position in the spectroscope. We then noted the alpha and beta bands also. Subsequently scanning his lenses with the recording spectrophotometer we found that his lenses had general absorptive properties in the visible spectrum with two peaks at 572 nm and 586 nm.

A set of commonly used tinged ophthalmic lenses were obtained and the properties of their absorptivity was noted.

Crookes $A_1$, Crookes $A_2$, Crookes $B_1$ and Crookes $B_2$ all had absorption peaks at 572 nm and 586 nm. Though Crookes $B_2$ showed less transmittance than the preceding three lenses.

Calobar B, Calobar C and Calobar D showed general absorption mainly around 600 nm to 700 nm and wavelengths less than 500 nm. Calobar D showed less transmittance.

Softlite 1 and Softlite 2 showed general absorptivity with no particular peaks and the transmittance were greater than 80%.

Cruxite AX showed similar properties as Softlite.

## DISCUSSION

Workers have noted that effects of tinted ophthalmic media can cause problems. (Clark 1968; Carlyle and Percy 1972). We would recommend that laboratory workers who wear absorptive lenses check their characteristics especially workers with Crookes $A_1$, $A_2$ and Crookes $B_1$, $B_2$ types of lenses.

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* *Communication to Editor*

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# Proper Motions in the Region of the Galactic Cluster NGC 4755

DAVID S. KING

ABSTRACT. Relative proper motions in the region of the galactic cluster NGC 4755 are determined with the aim of identifying stars which are non-members. The relative proper motions have an average standard error of 0".06/century and reveal 89 likely members and 75 likely non-members.

## INTRODUCTION

The open cluster NGC 4755 (R.A. = $12^h\ 50^m.6$, Dec. = $-60^\circ 04'$; 1950) has been studied photometrically by Arp (1958). The present investigation seeks to identify from their proper motions, those stars that are not members of the cluster.

## THE PLATES

The plates were taken with the 33cm standard astrograph (scale 1' = 1 mm) as follows:

| | Plate No. | Date Taken | Exposure | Plate Pair |
|---|---|---|---|---|
| 1 | 43s | 1892 May 21 | 10 m | 1 |
| 2 | 43s | 1892 May 21 | 5 m | 2 |
| 3 | 1412s | 1894 Apr. 16 | 4 m | 3 |
| 4 | 2893s | 1896 Apr. 14 | 30 m | 4 |
| 5 | 554RH | 1909 May 18 | 4 m | 5 |
| 6 | 7985Sa | 1980 Mar. 17 | 20 m | 1 |
| 7 | 7986Sa | 1980 Mar. 17 | 12 m | 2 |
| 8 | 7992Sa | 1980 Mar. 18 | 20 m | 4 |
| 9 | 7993Sa | 1980 Mar. 18 | 12 m | 5 |
| 10 | 7998Sa | 1980 Mar. 20 | 12 m | 3 |

Plate pairs 1 and 2 were centred at R.A. $12^h 48^m$ Dec. $-60^\circ 00'$. Plate pair 3 was centred at R.A. $12^h 54^m$ Dec. $-59^\circ 00'$. Plate pairs 4 and 5 were centred at R.A. $12^h 42^m$ Dec. $-59^\circ 00'$ (All 1900).

## MEASUREMENT

The plates were each measured in a Grubb-Parsons photoelectric measuring machine in both direct and reverse positions. The reverse positions were converted into direct measures using plate constants and the average was recorded. All stars measured were selected from the published coordinates in the Astrographic Catalogue (Sydney Observatory 1954, plate 43s).

## REDUCTIONS AND PROBABILITIES

The method of reduction and calculation of membership probabilities is described in a previous paper (King 1979). The distribution parameters in arc sec./century after eliminating 16 stars to obtain the best fit were:

$$\theta = -0^\circ.87 \quad N_f = 59 \quad X_f = -0.109 \quad \Sigma_x = 0.420$$
$$\sigma_c = 0.124 \quad N_c = 89 \quad Y_f = 0.023 \quad \Sigma_y = 0.318$$

$\theta$ is the rotation angle of the observed proper motions ($+\mu$ to $+\nu$) into a new coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions. All the other parameters are defined in this new coordinate system. $\sigma_c$ is the dispersion of the cluster star motions; $N_f$, $N_c$ are the number of field and cluster stars. $X_f$, $Y_f$ the centre of the field star proper motion distribution; $\Sigma_x$, $\Sigma_y$ the field star proper motion dispersions.

The standard errors for individual stars have been grouped by their magnitudes, and the mean of the standard errors $\sigma_\mu$, $\sigma_\nu$ determined for different ranges are as follows:

| Magnitude | $\sigma_\nu$ (Unit 0".01/cent) | $\sigma_\nu$ | No. of stars |
|---|---|---|---|
| 11.5 - 11.9 | 5.11 | 4.48 | 71 |
| 11.0 - 11.4 | 7.48 | 7.62 | 52 |
| 10.0 - 10.9 | 7.11 | 6.39 | 18 |
| 9.0 - 9.9 | 8.75 | 8.58 | 12 |
| 5.5 - 8.9 | 7.55 | 10.00 | 11 |
| All | 6.51 | 6.35 | 164 |

The absolute **proper** motion of the cluster NGC 4755 by comparison with 19 Cape Catalogue stars is $-0.26 \pm 0.20''$/cent. in R.A. and $+0.05 \pm 0.19''$/cent. in Dec.

The observational data follows in table 1. The various columns are:

| | |
|---|---|
| No. | The number from the Astrographic Catalogue, Sydney Section (centre $12^h 48^m$ $-60^\circ$; 1900) |
| Mag. | The magnitude of the star taken from either the Cape Photographic Catalogue or the Sydney Astrographic Catalogue. |
| R.A. | Right ascension (1950), all prefixed by $12^h$. |
| Dec. | Declination (1950). |
| CPD No. | Cape Photographic Durchmusterung number. |
| V | Photovisual magnitude from Mermilliod. |
| M No. | Number as given in Mermilliod's Catalogue. |
| $\mu,\nu$ | Centennial proper motion in units of 0".01/cent. Motion of $\mu$ in R.A. and $\nu$ in Dec. |
| $\sigma_\mu,\sigma_\nu$ | Standard errors of centennial proper motion in units of 0".01/cent. |
| P | Probability of membership in NGC 4755. |
| Notes | 2 - Only 2 plate pairs used. |
| | 6 - Not used in the calculation of distribution parameters. |

## REFERENCES

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King, D.S., 1979. *J. Roy. Soc. N.S.W.*, *112*, 101-104.
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TABLE 1

THE OBSERVATIONAL DATA

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | μ | ν | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 451 | 9.9 | 52 44 | -60 17 58 | 4583 | | | 17 | -15 | 12 | 8 | 78 | |
| 452 | 11.9 | 52 10 | -60 19 24 | | | | -140 | -48 | 5 | 2 | 0 | 2,6 |
| 453 | 11.3 | 51 33 | -60 21 09 | | | | 24 | 4 | 2 | 2 | 73 | 2 |
| 455 | 11.6 | 50 59 | -60 21 28 | | | | 2 | -14 | 2 | 1 | 89 | 2 |
| 456 | 11.2 | 50 48 | -60 18 23 | | | | 5 | -42 | 2 | 8 | 10 | 2 |
| 457 | 11.2 | 50 38 | -60 21 34 | | | | -71 | 65 | 6 | 17 | 0 | |
| 458 | 10.7 | 50 11 | -60 18 52 | | | | -1022 | -221 | 5 | 5 | 0 | 2,6 |
| 459 | 9.4 | 49 53 | -60 17 28 | 4516 | | | -78 | -33 | 12 | 10 | 0 | |
| 462 | 10.4 | 49 11 | -60 19 46 | | | | -101 | -78 | 12 | 3 | 0 | 6 |
| 464 | 9.3 | 49 02 | -60 16 43 | 4504 | | | - 8 | -21 | 10 | 12 | 77 | |
| 465 | 9.4 | 49 01 | -60 20 45 | 4503 | | | -29 | -27 | 9 | 12 | 12 | |
| 466 | 11.0 | 48 20 | -60 17 50 | | | | 107 | -17 | 9 | 12 | 0 | 6 |
| 510 | 10.0 | 52 39 | -60 12 16 | 4581 | | | -10 | -10 | 6 | 2 | 88 | |
| 511 | 11.6 | 52 13 | -60 16 06 | | | | 4 | 30 | 1 | 5 | 50 | |
| 512 | 11.9 | 51 52 | -60 15 16 | | | | 69 | 15 | 1 | 10 | 0 | 2 |
| 513 | 11.9 | 51 51 | -60 15 30 | | | | -46 | 59 | 4 | 3 | 0 | 2 |
| 514 | 11.6 | 51 28 | -60 13 34 | | | | 18 | 27 | 2 | 2 | 42 | 2 |
| 515 | 11.9 | 51 16 | -60 14 24 | | | | -118 | -11 | 10 | 1 | 0 | 2,6 |
| 517 | 11.6 | 48 54 | -60 15 30 | | | | -95 | -144 | 1 | 1 | 0 | 2,6 |
| 519 | 10.0 | 48 38 | -60 13 28 | 4498 | | | -16 | 3 | 7 | 6 | 85 | |
| 520 | 11.3 | 48 36 | -60 12 06 | 4496 | | | -47 | 23 | 13 | 10 | 0 | |
| 521 | 11.3 | 48 24 | -60 12 12 | | | | 5 | -24 | 15 | 6 | 73 | |
| 570 | 11.6 | 52 33 | -60 09 28 | | | | 9 | 0 | 6 | 8 | 92 | |
| 571 | 11.6 | 52 12 | -60 08 58 | | | | 20 | -38 | 1 | 1 | 9 | 2 |
| 572 | 11.0 | 52 07 | -60 08 14 | 4577 | | | - 9 | 28 | 9 | 4 | 52 | |
| 573 | 11.4 | 51 44 | -60 08 58 | | | | -17 | - 3 | 6 | 10 | 83 | |
| 574 | 11.6 | 51 32 | -60 08 57 | | | | 9 | -11 | 9 | 8 | 89 | |
| 575 | 11.6 | 51 32 | -60 09 45 | | | | 48 | -24 | 3 | 1 | 0 | 2 |
| 576 | 11.6 | 51 32 | -60 11 15 | | | | - 4 | -16 | 1 | 1 | 86 | 2 |
| 578 | 11.6 | 51 14 | -60 10 38 | | | | -10 | -51 | 3 | 6 | 1 | 2 |
| 580 | 11.3 | 51 07 | -60 06 57 | 4569 | | | 8 | -23 | 6 | 11 | 74 | |
| 581 | 11.0 | 51 03 | -60 09 04 | 4568 | | | -22 | 16 | 9 | 11 | 57 | |
| 582 | 11.3 | 51 00 | -60 10 04 | 4567 | | | 1 | 25 | 9 | 13 | 69 | |
| 583 | 11.2 | 50 58 | -60 07 06 | 4565 | 10.78 | 311 | 13 | 5 | 7 | 4 | 89 | |
| 584 | 8.9 | 50 57 | -60 08 41 | 4564 | 9.07 | 6 | 0 | - 6 | 3 | 5 | 92 | |
| 585 | 11.0 | 50 56 | -60 10 16 | 4563 | | | 4 | 8 | 12 | 11 | 92 | |
| 586 | 11.6 | 50 53 | -60 06 50 | | | | 39 | -29 | 9 | 13 | 2 | |
| 587 | 11.6 | 50 53 | -60 07 41 | | | | 18 | 24 | 3 | 3 | 52 | 2 |
| 588 | 11.4 | 50 52 | -60 07 37 | 4561 | 10.19 | 306 | 15 | 1 | 7 | 8 | 88 | |
| 589 | 10.7 | 50 51 | -60 07 00 | 4559 | 8.43 | 305 | -10 | 0 | 8 | 3 | 90 | |
| 590 | 9.4 | 50 49 | -60 06 46 | 4557 | 10.22 | 203 | 2 | 9 | 19 | 16 | 91 | 2 |
| 591 | 11.3 | 50 47 | -60 09 01 | 4554 | | | -13 | -10 | 10 | 5 | 85 | |
| 592 | 8.2 | 50 46 | -60 07 55 | 4552 | 8.35 | 5 | - 2 | 12 | 3 | 12 | 90 | |
| 593 | 11.3 | 50 43 | -60 07 45 | 4548 | | | 0 | 10 | 5 | 8 | 91 | |
| 594 | 11.6 | 50 43 | -60 07 35 | | | | - 4 | - 1 | 3 | 1 | 93 | 2 |
| 595 | 11.4 | 50 42 | -60 08 21 | | | | 8 | - 1 | 13 | 9 | 92 | |
| 597 | 11.3 | 50 40 | -60 07 10 | | | | -20 | 14 | 6 | 5 | 67 | |
| 598 | 10.0 | 50 39 | -60 07 27 | 4546 | 9.76 | 417 | 0 | 3 | 7 | 6 | 93 | |
| 599 | 11.9 | 50 38 | -60 09 54 | | | | -88 | 31 | 5 | 3 | 0 | 2 |
| 600 | 11.9 | 50 38 | -60 09 43 | | | | - 3 | -20 | 2 | 10 | 82 | 2 |
| 601 | 11.6 | 50 37 | -60 07 25 | | | | 22 | -36 | 2 | 2 | 10 | 2 |
| 602 | 11.6 | 50 37 | -60 09 10 | | | | -20 | 26 | 10 | 1 | 34 | |
| 603 | 9.9 | 50 35 | -60 07 30 | 4542 | 9.86 | 418 | 3 | - 3 | 4 | 3 | 93 | |
| 605 | 11.9 | 50 33 | -60 08 04 | | | | -14 | -44 | 1 | 8 | 4 | 2 |
| 606 | 10.0 | 50 33 | -60 08 16 | 4540 | | | - 8 | - 2 | 4 | 5 | 91 | |
| 607 | 11.6 | 50 33 | -60 10 54 | | | | -13 | 15 | 7 | 1 | 80 | 2 |
| 609 | 11.9 | 50 29 | -60 09 58 | | | | -40 | 120 | 1 | 1 | 0 | 2,6 |
| 610 | 10.7 | 50 26 | -60 06 42 | 4535 | 10.26 | 414 | 4 | - 9 | 11 | 10 | 91 | |
| 611 | 11.3 | 50 23 | -60 07 30 | 4530 | 11.42 | 11 | 28 | 8 | 13 | 8 | 56 | |
| 613 | 9.9 | 50 21 | -60 06 59 | 4528 | 9.79 | 7 | - 8 | 1 | 3 | 4 | 91 | |
| 614 | 11.6 | 50 18 | -60 07 09 | | | | -12 | - 2 | 1 | 1 | 89 | 2 |
| 615 | 11.6 | 50 17 | -60 09 54 | | | | -16 | 14 | 2 | 5 | 76 | |
| 616 | 10.4 | 50 14 | -60 11 21 | 4526 | | | -21 | - 4 | 4 | 8 | 75 | |
| 617 | 11.3 | 50 14 | -60 07 56 | 4525 | | | -101 | -10 | 1 | 2 | 0 | |
| 618 | 10.4 | 50 10 | -60 09 42 | 4523 | | | -12 | 3 | 4 | 4 | 89 | |

Table 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | μ | ν | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 619 | 11.4 | 50 10 | -60 07 56 | 4524 | | | - 7 | -14 | 6 | 9 | 87 | |
| 620 | 11.0 | 50 01 | -60 06 52 | 4520 | | | - 5 | - 1 | 8 | 4 | 92 | |
| 621 | 11.3 | 49 51 | -60 09 19 | | | | 8 | -27 | 8 | 7 | 62 | |
| 622 | 11.9 | 49 47 | -60 09 46 | | | | 10 | -13 | 2 | 15 | 87 | 2 |
| 623 | 11.9 | 49 43 | -60 09 12 | | | | -14 | 20 | 4 | 1 | 68 | |
| 624 | 11.0 | 49 36 | -60 09 46 | 4512 | | | - 1 | 8 | 8 | 6 | 92 | |
| 625 | 11.3 | 49 34 | -60 06 44 | 4511 | | | -187 | -213 | 1 | 12 | 0 | 2,6 |
| 626 | 11.7 | 49 24 | -60 07 24 | | | | -567 | 70 | 1 | 7 | 0 | 2,6 |
| 627 | 11.6 | 49 17 | -60 06 59 | | | | 28 | -31 | 5 | 7 | 11 | 2 |
| 628 | 11.6 | 49 15 | -60 09 30 | | | | -45 | 42 | 1 | 4 | 0 | 2 |
| 629 | 10.0 | 48 53 | -60 08 03 | 4502 | | | 5 | 4 | 4 | 3 | 92 | |
| 630 | 11.6 | 48 41 | -60 09 21 | | | | 8 | 0 | 2 | 1 | 92 | 2 |
| 631 | 11.6 | 48 41 | -60 10 57 | | | | 4 | - 4 | 1 | 1 | 93 | 2 |
| 632 | 11.3 | 48 37 | -60 09 59 | 4497 | | | 23 | 25 | 10 | 10 | 35 | |
| 633 | 9.1 | 47 58 | -60 10 31 | 4488 | | | 10 | 9 | 6 | 8 | 89 | |
| 635 | 6.8 | 47 13 | -60 07 41 | 4483 | | | -94 | -61 | 6 | 6 | 0 | 6 |
| 662 | 11.0 | 52 44 | -60 06 14 | 4584 | | | - 9 | - 1 | 8 | 8 | 91 | |
| 663 | 11.0 | 52 41 | -60 03 49 | 4582 | | | -304 | -42 | 12 | 7 | 0 | 6 |
| 664 | 11.6 | 52 24 | -60 03 00 | | | | -455 | -58 | 2 | 6 | 0 | 2,6 |
| 666 | 11.9 | 51 55 | -60 03 48 | | | | 52 | 35 | 5 | 2 | 0 | 2 |
| 667 | 11.6 | 51 44 | -60 03 16 | | | | - 5 | -19 | 1 | 8 | 82 | 2 |
| 668 | 11.6 | 51 36 | -60 03 07 | | | | 10 | -10 | 3 | 6 | 89 | 2 |
| 669 | 11.3 | 51 14 | -60 05 31 | 4571 | | | -49 | - 1 | 5 | 12 | 1 | |
| 670 | 11.6 | 51 09 | -60 05 54 | | | | -40 | -20 | 6 | 5 | 3 | 2 |
| 671 | 11.6 | 51 08 | -60 05 22 | 4570 | | | 13 | - 2 | 7 | 9 | 90 | |
| 672 | 6.8 | 51 00 | -60 03 51 | 4566 | 6.80 | 3 | 9 | 5 | 4 | 8 | 91 | |
| 673 | 11.6 | 50 58 | -60 05 06 | | | | 6 | - 3 | 3 | 3 | 92 | |
| 674 | 11.6 | 50 56 | -60 05 24 | | | | 22 | -16 | 10 | 3 | 65 | 2 |
| 675 | 11.0 | 50 53 | -60 05 14 | 4562 | 10.06 | 202 | 0 | 13 | 4 | 4 | 89 | |
| 677 | 10.0 | 50 52 | -60 05 59 | 4558 | 9.37 | 201 | - 7 | - 1 | 8 | 5 | 92 | |
| 678 | 10.7 | 50 52 | -60 05 42 | | | | - 5 | 5 | 6 | 4 | 92 | |
| 679 | 11.6 | 50 51 | -60 05 00 | | | | 34 | 9 | 2 | 2 | 29 | |
| 680 | 11.9 | 50 51 | -60 02 59 | | | | 76 | - 4 | 4 | 1 | 0 | 2 |
| 682 | 11.6 | 50 49 | -60 04 41 | | | | 12 | -26 | 6 | 1 | 61 | |
| 683 | 11.3 | 50 49 | -60 06 27 | | | | -20 | 37 | 8 | 7 | 7 | |
| 684 | 5.6 | 50 49 | -60 06 17 | 4555 | 5.90 | 2 | -27 | - 7 | 14 | 15 | 54 | |
| 685 | 11.6 | 50 49 | -60 04 22 | | | | -25 | 64 | 8 | 11 | 0 | 2 |
| 687 | 11.0 | 50 48 | -60 05 37 | 4556 | | | 20 | 8 | 4 | 5 | 79 | |
| 688 | 8.0 | 50 47 | -60 03 38 | 4551 | 7.93 | 223 | 14 | - 2 | 7 | 11 | 89 | |
| 689 | 10.4 | 50 47 | -60 06 02 | 4553 | 9.56 | 18 | -15 | 14 | 15 | 15 | 78 | |
| 690 | 10.4 | 50 47 | -60 02 19 | 4550 | 10.01 | 9 | 7 | - 4 | 5 | 8 | 92 | |
| 691 | 10.4 | 50 46 | -60 06 02 | | | | -21 | 17 | 3 | 14 | 58 | |
| 692 | 10.4 | 50 46 | -60 03 31 | | | | 28 | -23 | 10 | 10 | 28 | |
| 693 | 11.6 | 50 45 | -60 04 51 | | | | - 1 | 46 | 5 | 1 | 3 | 2 |
| 694 | 11.3 | 50 44 | -60 04 41 | | | | 2 | - 6 | 6 | 6 | 92 | |
| 695 | 9.9 | 50 44 | -60 06 12 | 4549 | 9.74 | 301 | - 6 | 12 | 6 | 6 | 88 | |
| 696 | 11.3 | 50 43 | -60 04 30 | | | | - 7 | 19 | 9 | 12 | 80 | |
| 697 | 11.6 | 50 42 | -60 06 34 | | | | 0 | 45 | 2 | 10 | 4 | |
| 699 | 9.0 | 50 41 | -60 04 41 | 4547 | 7.66 | 4 | 11 | 17 | 11 | 9 | 81 | |
| 702 | 11.4 | 50 39 | -60 06 23 | | | | - 2 | 2 | 7 | 5 | 93 | |
| 703 | 8.9 | 50 39 | -60 04 56 | | | | - 6 | 8 | 5 | 9 | 91 | |
| 705 | 10.4 | 50 38 | -60 06 22 | 4544 | 10.27 | 405 | 11 | 5 | 9 | 4 | 90 | |
| 707 | 6.8 | 50 38 | -60 05 08 | 4543 | 6.90 | 106 | 0 | - 4 | 7 | 4 | 93 | |
| 708 | 11.6 | 50 37 | -60 06 38 | | | | -12 | 16 | 13 | 1 | 79 | |
| 709 | 11.9 | 50 36 | -60 04 15 | | | | 4 | 31 | 16 | 5 | 46 | |
| 710 | 11.9 | 50 36 | -60 05 31 | | | | - 6 | 32 | 7 | 1 | 39 | 2 |
| 711 | 11.6 | 50 34 | -60 04 55 | | | | - 8 | 52 | 13 | 4 | 1 | 2 |
| 712 | 11.0 | 50 34 | -60 04 43 | 4541 | 10.39 | 115 | 8 | - 2 | 6 | 3 | 92 | |
| 715 | 11.6 | 50 32 | -60 06 22 | | | | -18 | - 2 | 8 | 10 | 82 | |
| 716 | 11.6 | 50 32 | -60 06 03 | | | | 13 | -26 | 1 | 1 | 59 | 2 |
| 718 | 11.3 | 50 30 | -60 05 00 | 4539 | | | 3 | 32 | 4 | 6 | 42 | |
| 719 | 11.9 | 50 28 | -60 06 20 | | | | 64 | 13 | 3 | 7 | 0 | 2 |
| 720 | 11.6 | 50 27 | -60 02 43 | 4536 | | | -12 | - 4 | 3 | 16 | 89 | |
| 722 | 11.3 | 50 26 | -60 04 31 | 4537 | 10.58 | 10 | 14 | - 2 | 10 | 7 | 89 | |
| 723 | 11.0 | 50 26 | -60 05 43 | 4532 | 10.23 | 113 | 12 | 0 | 4 | 6 | 90 | |
| 724 | 11.3 | 50 25 | -60 02 54 | | | | -11 | 5 | 11 | 6 | 89 | |
| 725 | 11.6 | 50 25 | -60 04 03 | | | | 15 | 71 | 6 | 4 | 0 | 2 |

Table 1 continued

| No. | Mag. | R.A. | Dec. | CPD No. | V | M No. | $\mu$ | $\nu$ | $\sigma_\mu$ | $\sigma_\nu$ | P | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 726 | 11.3 | 50 24 | -60 05 14 | 4531 | | | 9 | -10 | 7 | 6 | 90 | |
| 727 | 11.6 | 50 23 | -60 02 19 | | | | -20 | -17 | 3 | 1 | 63 | 2 |
| 728 | 5.5 | 50 22 | -60 03 25 | 4529 | 5.76 | 1 | 13 | 35 | 7 | 14 | 22 | |
| 729 | 11.9 | 50 20 | -60 05 14 | | | | -82 | -28 | 7 | 2 | 0 | 2 |
| 731 | 11.2 | 50 10 | -60 06 10 | 4522 | | | 9 | 24 | 9 | 11 | 68 | |
| 732 | 11.6 | 50 09 | -60 05 05 | | | | 19 | -41 | 5 | 3 | 5 | 2 |
| 733 | 11.6 | 49 57 | -60 03 04 | | | | -12 | -17 | 13 | 4 | 79 | |
| 734 | 11.0 | 49 54 | -60 06 25 | 4517 | | | -12 | 2 | 6 | 6 | 89 | |
| 736 | 11.2 | 49 39 | -60 04 01 | 4515 | | | -10 | 15 | 4 | 4 | 83 | |
| 737 | 11.0 | 49 37 | -60 02 07 | 4513 | | | 1 | 1 | 7 | 7 | 93 | |
| 738 | 11.6 | 48 40 | -60 03 01 | | | | 14 | 2 | 3 | 4 | 89 | 2 |
| 740 | 11.9 | 48 20 | -60 06 08 | | | | -179 | 26 | 8 | 6 | 0 | 2,6 |
| 741 | 5.9 | 48 19 | -60 03 28 | 4494 | 5.74 | 20 | - 4 | 20 | 16 | 14 | 80 | |
| 742 | 11.4 | 48 15 | -60 05 55 | 4493 | | | -54 | -12 | 10 | 9 | 0 | |
| 771 | 9.1 | 52 21 | -60 01 05 | 4579 | | | -77 | -34 | 10 | 8 | 0 | |
| 773 | 11.6 | 52 03 | -59 59 20 | | | | -15 | 3 | 10 | 4 | 86 | |
| 774 | 11.6 | 51 43 | -59 59 59 | | | | 19 | - 4 | 14 | 13 | 83 | |
| 775 | 11.6 | 51 32 | -60 00 08 | | | | -69 | 7 | 8 | 1 | 0 | |
| 776 | 11.3 | 51 22 | -59 56 58 | | | | -16 | 3 | 8 | 10 | 85 | |
| 777 | 11.3 | 50 26 | -60 00 01 | 4534 | | | -34 | - 4 | 11 | 9 | 25 | |
| 778 | 11.0 | 49 58 | -60 01 06 | 4519 | | | 2 | - 2 | 6 | 5 | 93 | |
| 779 | 11.6 | 49 55 | -59 58 58 | | | | -10 | - 1 | 7 | 4 | 90 | |
| 781 | 11.3 | 49 38 | -59 58 44 | 4514 | | | 2 | -13 | 6 | 9 | 90 | |
| 782 | 11.6 | 48 57 | -59 58 06 | | | | 32 | -48 | 12 | 3 | 0 | 2 |
| 783 | 11.6 | 48 51 | -59 58 19 | | | | -77 | -45 | 1 | 3 | 0 | 2 |
| 801 | 8.1 | 53 58 | -59 52 20 | 4601 | | | -1723 | -323 | 11 | 12 | 0 | 6 |
| 804 | 11.6 | 50 56 | -59 52 16 | | | | -114 | -22 | 14 | 10 | 0 | |
| 805 | 11.6 | 50 34 | -59 55 28 | | | | -209 | -110 | 1 | 7 | 0 | 2,6 |
| 806 | 9.4 | 50 27 | -59 55 43 | 4538 | | | 1 | - 8 | 3 | 7 | 92 | |
| 807 | 11.0 | 50 18 | -59 54 12 | 4527 | | | -24 | -22 | 7 | 8 | 37 | |
| 808 | 11.4 | 49 01 | -59 53 44 | 4505 | | | 17 | -10 | 9 | 6 | 83 | |
| 809 | 11.6 | 48 21 | -59 53 59 | | | | -101 | -79 | 12 | 1 | 0 | 6 |

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# Nuclear Magnetic Resonance in Polymer Studies*

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ABSTRACT. $^{13}C$ nmr spectroscopy is now extensively used in both synthetic and biological polymer studies. Structural and dynamic properties of a polymer can be determined from the $^{13}C$ nmr chemical shift and relaxation time parameters. Examples from both the synthetic and biological fields are presented together with descriptions of new techniques for the analysis of end groups and the determination of tacticity in synthetic polymers.

## INTRODUCTION

In his will the late Professor A. Liversidge requested that this lecture should be "for the encouragement of research in Chemistry....and shall not be such as are termed popular lectures dealing with generalities....but shall be such as will primarily encourage research and stimulate the lecturer and the public to think and acquire new knowledge by research instead of merely giving instructions". Further he directed that "the lecture shall be upon recent researches and discoveries and the most important part of the lecturers' duty shall be to point in which direction further researches are necessary and how he thinks they can best be carried out".

I hope to fulfill these requirements in this lecture by describing some of our recent work in the field of synthetic and biological polymers using the versatile physical technique, nuclear magnetic resonance (nmr) spectroscopy. In the past 35 years the nmr technique has crossed many discipline barriers. After its discovery and initial description by physicists in the mid 1940's (Block, 1946; Purcell, 1946), chemists and particularly organic chemists, have developed the technique over the next 30 years into a powerful tool for the study of structure and motion within organic molecules. The method is now used extensively in the fields of polymer and biological sciences and it is some of these applications I wish to discuss today.

I shall concentrate on $^{13}C$ nmr and after an initial introduction to the technique and a description of the two most important parameters of chemical shift and relaxation time, I shall discuss some of our recent research. Firstly I shall describe our work dealing with structural studies of synthetic polymers, and with new methods for the analysis of end groups and for the determination of the tacticity of synthetic polymers. I shall then turn to our studies of biological polymers, and in particular to the use of relaxation times in the study of motion and interaction in lipid bilayers. We expect that this work should lead to an understanding of lipid/protein interactions and the overall function of biological membranes.

* *The Liversidge Research Lecture, delivered before the Royal Society of New South Wales, 19th June, 1980.*

## $^{13}C$ NMR THEORY

The $^{13}C$ nucleus has a quantum spin number of ½ and when a nucleus is placed in an applied magnetic field ($H_o$) it precesses about the field with a characteristic frequency, $\omega_o$, (its Larmor frequency) such that $\omega_o = -\gamma H_o$ where $\gamma$ is the gyromagnetic ratio of the $^{13}C$ nucleus (Figure 1).

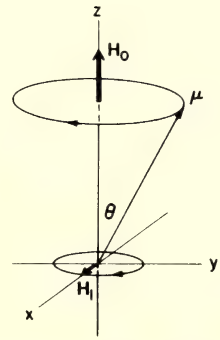



Figure 1. Precession of a magnetic moment $\mu$ about a fixed magnetic field $H_o$.

In practice we never study a single nucleus but rather a collection of nuclei. Some nuclei precess in the direction of the applied field and some opposed to the field. At thermal equilibrium there are more aligned in the direction of the field (the lower energy state) than opposed which results in a net magnetisation (M) along the direction of $H_o$ (conventionally the z axis). (Figure 2).

The resonance condition in an nmr experiment is achieved by applying a second oscillating radio-frequency (rf) field ($H_1$) at right angles to $H_o$. Resonance occurs with an absorption of energy when the frequency of $H_1$ equals the Larmor frequency of the nucleus.

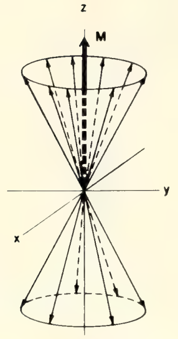



Figure 2. Precession of a collection of identical nuclei with net macroscopic magnetisation (M) along the z axis.

The motion of the net magnetisation under the influence of two different fields, $H_o$ and $H_1$, is extremely complicated in the normal laboratory frame of reference and to simplify the discussion of pulsed nmr and relaxation times, it is convenient to consider the motion of M in a co-ordinate system rotating about $H_o$ at the angular frequency $\omega_0$. This new co-ordinate system, designated x', y', z', is called the rotating frame. In the laboratory frame, $H_1$ is rotating in the xy plane but in the rotating frame this second field is fixed and, by convention, fixed along the x' axis. Again, by convention, the receiver is placed at right angles to the transmitter i.e. along the y' axis.

When an intense rf pulse ($H_1$) is applied for time $t_p$ the magnetisation $M_0$ along z' will begin to precess about the new field ($H_1$) and in fact rotate through an angle $\Theta$ radians where $\Theta = \gamma H_1 t_p$ (Figure 3).

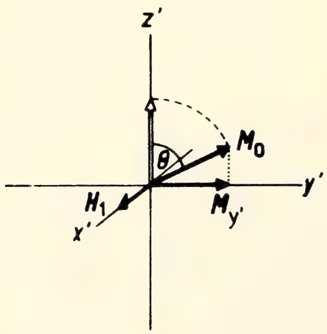



Figure 3. Rotation of magnetisation ($M_o$) around $H_1$ field.

By varying $t_p$ it is possible to rotate the magnetisation through any desired angle.

After the pulse is turned off the spin system will relax back to its equilibrium position ($M_o$) according to two rate equations.

$$\frac{dM_{z'}}{dt} = -\frac{(M_{z'} - M_o)}{T_1}$$

$$\frac{dM_{y'}}{dt} = -\frac{M_{y'}}{T_2^*}$$

where $T_1$ and $T_2^*$ are the longitudinal and transverse relaxation times respectively.

The signal in the Pulsed Fourier Transform (PFT) experiment is detected in the y' axis and is given by

$$M_{y'} = M_o \sin\Theta e^{-t/T_2^*}$$

Obviously, the maximum signal is observed when $\Theta = \pi/2$ ($90^0$) i.e. when $\sin\Theta = 1$. If we plot the signal strength versus time we have a free induction decay (FID) or time domain spectrum (Figure 4), which on Fourier transformation gives a frequency domain spectrum. This is the case for a collection of nuclei irradiated at the Larmor frequency ($\omega_o$).

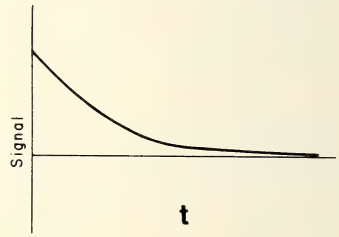



Figure 4. Experimental FID of magnetisation along y' axis.

However, if the pulse frequency is slightly off-resonance by $\Delta\nu$ (as is the usual case) the FID will be modulated by a term $\cos 2\pi\Delta\nu t$ which gives a modulated FID (Figure 5) given by

$$M_{y'} = M_o \sin\Theta e^{-t/T_2^*} \cos 2\pi\Delta\nu t$$

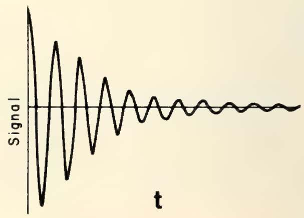



Figure 5. Modulated FID for off-resonance signal.

Because of the non uniform distribution of electrons within an organic molecule, nuclei in different chemical environments within the molecule resonate at slightly different frequencies. Therefore, in a normal nmr experiment, we obtain a series of modulated FID's i.e. an interferrogram and this signal is given by

$$M_{y'} = \sum_i M_o \sin\Theta_i e^{-t/T_2^*} \cos 2\pi\Delta\nu_i t$$

Fourier transformation of such an interferrogram gives a frequency domain spectrum made up of a number of resonance signals. These chemically induced differences in frequency, the chemical shift, are not recorded in absolute frequency units, but rather, in the form of a dimensionless quantity ($\delta$) defined with respect to the observing frequency

$$\delta = \frac{H_C - H_R}{H_o} \times 10^6 \text{ ppm}$$

The reference standard is usually tetramethyl silane, arbitrarily set at $\delta$=0.00 ppm.

Experimentally, it is easier to measure the longitudinal relaxation time, $T_1$ than the transverse relaxation time, $T_2^*$. A number of multiple pulse sequences can be used but the most common is the so called 'inversion/recovery' method (Vold, 1968) which involves a $180^0$-$\tau$-$90^0$ pulse sequence (Figure 6).

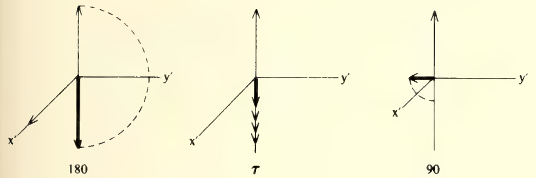



Figure 6. Determination of $T_1$ by $180^0$-$\tau$-$90^0$ pulse sequence.

The first $180^0$ pulse applied along the x' axis inverts the magnetisation into the -z' axis. Longitudinal relaxation occurs causing $M_{z'}$ to change from a value of $-M_o$ through zero to the equilibrium value $M_o$ with time. If at a time t, after the $180^0$ pulse, a $90^0$ pulse is applied along x', $M_{z'}$ (t) is rotated into the y' axis and a FID is detected. For signal averaging purposes, relaxation must be complete before the pulse train is repeated. Usually a time T is set such that $T=5xT_1$ and the pulse train $(180^0\text{-}\tau\text{-}90^0\text{-}T)_n$ is used. The equation of motion of $M_{z'}$ is given by

$$\frac{dM_{z'}}{dt} = \frac{(M_{z'} - M_o)}{T_1}$$

At time t=0, $M_{z'} = -M_o$

Integration yields

$$M_{z'}(t) = M_o\ (1-2e^{-t/T_1})$$

This equation is usually rewritten in the form

$$\ln(A_\infty - A_t) = \ln 2\ A_\infty - t/T_1$$

where $A_t$ = signal amplitude at time t and $A_\infty$ = limiting amplitude at time $5xT_1$

$T_1$ is determined from a series of spectra (Figure 7) recorded at different t settings using either an exponential fit (Figure 8) or a linear fit and measurement of slope (Figure 9).

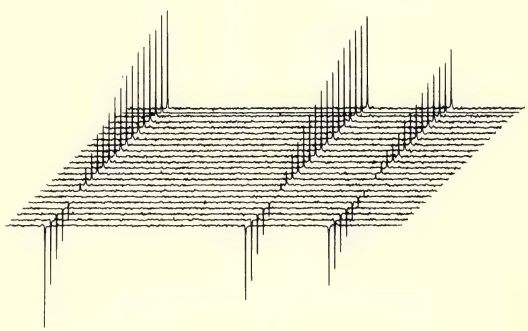


Figure 7. $^{13}C$ nmr $(180^0\text{-}\tau\text{-}90^0)$ spectra of n-propanol for t = 0.4 to 13.0 sec. in 0.6 sec. steps.

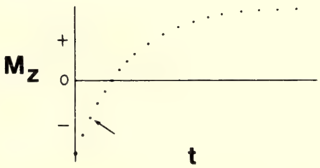



Figure 8. Exponential plot of signal intensity versus time in $(180^0\text{-}\tau\text{-}90^0)$ sequence.

It is possible to measure $T_1$ values of all the different carbon nuclei in a molecule by careful selection of t values.

In many cases the $T_1$ values, as measured, are inversely proportional to a correlation time ($\tau_c$) which is defined as the time a particular nucleus spends in a particular position before moving through one radian. The correlation time is therefore a direct measurement of motion of the nucleus.

$$\frac{1}{T_1} = \frac{Nh^2\gamma_C^2\gamma_H^2}{r^6} \cdot \tau_c$$

where N is the number of directly bound hydrogen atoms, and r is the C-H interatomic distance.

The $^{13}C$ chemical shift and longitudinal relaxation time parameters will both be used in the subsequent discussions on the nmr of polymers.

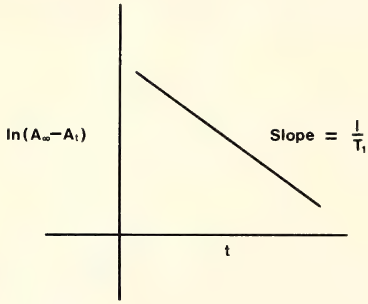



Figure 9. Linear plot of $\ln(A_\infty - A_t)$ versus time in $(180^0\text{-}\tau\text{-}90^0)$ sequence.

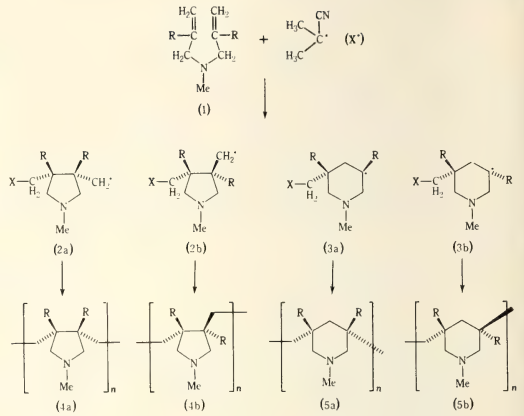


Diagram 1. Possible structures from cyanoisopropyl radical induced cyclopolymerization of diallylamines.

## Structure of Polymers

An organic molecule can be represented by a single structure and this structure can be readily determined by nmr measurements. In a polymer, the nmr spectrum represents an 'average molecule' from which we can determine overall structural features and also a monomer distribution e.g., the percentages of monomers as structural entities in homopolymers and a ratio of monomer A to monomer B in a copolymer (Randall, 1977).

As an example I wish to describe our work on the cyclopolymers used in the SIROTHERM process for the desalination of brackish water. Polymers for this process were derived by the cyanoisopropyl radical induced cyclopolymerization of diallylamines. Depending upon the initial position of attack and upon the subsequent cyclisation five, six or even seven membered ring structures are possible (Diagram 1). $^{13}C$ nmr can be used successfully to distinguish between these polymer possibilities. The proton decoupled $^{13}C$ nmr spectrum of the cyclopolymer from N-methyl-N,N-diallylamine (I,$R_1$ = $R_2$ = H) is shown in Figure 10, (Johns, 1976).

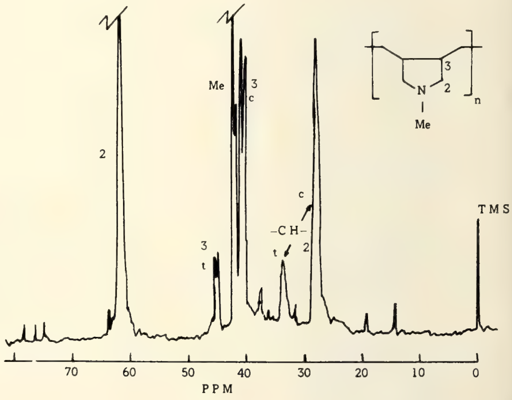



Figure 10. $^{13}C$ nmr spectrum of the polymer from N-methyl-N,N-diallylamine.

Comparison of this spectrum with those of a series of β,β-substituted pyrrolidines and piperidines (Hawthorne, 1976a) shows that the cyclic moieties in the polymer structure are of the pyrrolidine type (4a,4b) and no piperidine type units (5a,5b) are present. Specifically, N-methyl signals in the region 42.5-42.8 ppm can be assigned to N-methyls of *cis* and *trans*-pyrrolidine units and no signals are observed in the 47 ppm region for *cis* and *trans* piperidine. The overall structure is therefore that of a polypyrrolidine and not a polypiperidine.

A full assignment of the spectrum indicates a 5:1 ratio of *cis* and *trans*-polypyrrolidine. The downfield peak at 62.7 ppm can be assigned to the C2,5 methylene carbons of both *cis* and *trans*-pyrrolidine rings while the two peaks at 41.9 and 41.5 ppm can be assigned to the C3,4 methine carbons of the *cis*-substituted rings and the peaks at 45.9 and 45.5 ppm to the *trans*-substituted rings.

Similarly the remaining broadened peaks at 28.4 and 34.4 ppm can be assigned to the methylene carbons of the ethylene groups in the *cis* and *trans*-pyrrolidines respectively. The splitting of the C3,4 methine signals into pairs of signals in the *cis* and *trans*-structures depends upon the different dyad structures (Diagram 2) possible.

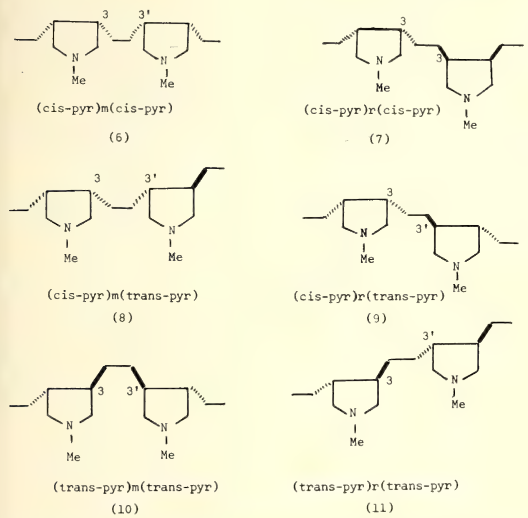



Diagram 2. Dyad structures of polypyrrolidines (4a,4b).

In considering the chemical shifts of the methine carbons in these different structures, it is convenient to focus attention on the "inner" methine carbons of each dyad (labelled 3 and 3' in each case). We propose that the chemical shift of any particular one of these carbons is determined primarily by the stereochemistry of the pyrrolidine unit in which it resides and secondarily by the relative chiralities of C3 and C3' of the appropriate dyad (Johns, 1976). On this basis, the methine carbons fall into two main groups, each of which has two subgroups

Group 1: Methine of *cis*-pyrrolidine units.

(a) those in which there is a *meso* relationship between C3 and C3'

C3 of (6), C3' of (6), and C3 of (8)

(b) those in which there is a *racemic* relationship

C3 of (7), C3' of (7), and C3 of (9)

Group 2: Methine of *trans*-pyrrolidine units.

(a) *meso* relationships between C3 and C3'

C3' of (8), C3 of (10), and C3' of (10)

(b) *racemic* relationships between C3 and C3'

C3' of (9), C3 of (11), and C3' of (11)

Two doublets are thus expected for the C3 signals in the average polymer spectrum.

A similar analysis of the spectrum (Figure 11) of the cyclopolymer from N-methyl-N,N-di-(2-methylallyl)amine (I,$R_1$ = $R_2$ = Me) reveals a mixture of both polypyrrolidine and polypiperidine structures in approximately equal amounts with signals from N-methyl groups at both 44.2 and 47.1 ppm (Johns, 1976). The complexity of this spectrum can be explained and the different signals assigned when the possible combinations of the two structural types are considered.

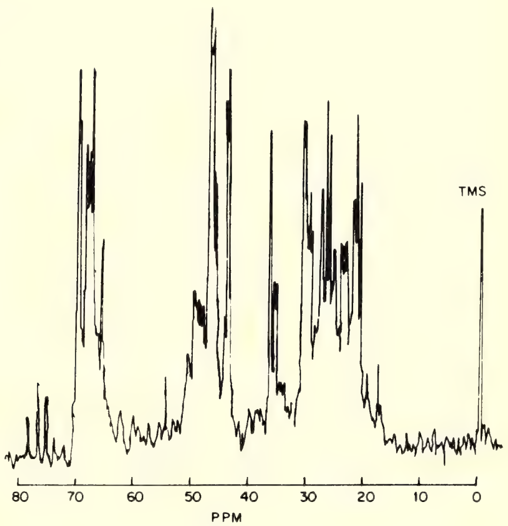



Figure 11. $^{13}$C nmr spectrum of the cyclopolymer from N-methyl-N,N-di-(2-methylallyl) amine.

Further studies (Hawthorne, 1975; Hawthorne, 1976b), on a series of polymers from N-methyl-N-allyl-N-(2-substituted allyl)amines have been made to determine the preferred site of initial radical addition to the diallylamine and the subsequent direction of cyclization. Steric interactions induced by β-substituents tend to favour attack at the unsubstituted allyl group whereas conjugated substituents favour attack at the substituted group with the consequent formation of conjugate-stabilized radicals. In all monosubstituted diallylamines, cyclization to the polypyrrolidine occurs except in the case of the t-butyl derivative where steric interactions induce cyclizations to both pyrrolidine and piperidine structures.

## End Group Analysis

The initiation and termination (end) groups can have a significant effect on the properties of a polymer. This is particularly so if the groups are reactive and can be involved in polymer degradation. However, the identification and estimation of the end groups is difficult because of their low overall concentration in our 'average' molecule as detected by nmr.

We have used an inversion/recovery technique similar to that employed in the determination of longitudinal relaxation times, to assign signals to those carbons of the initiation and termination groups (Hawthorne, 1979). Because of the restriction of motion along a polymer chain, the $T_1$ values of the backbone carbons of a cyclopolymer such as that from N-methyl-N,N-diallylamine (Figure 10) are expected to be quite short. By contrast the $T_1$ values of the carbons of the end groups of the polymer chain will be much longer because of their greater mobility.

By choosing a time t in an inversion/recovery, $180^0$-t-$90^0$, pulse sequence such that the backbone carbons with short $T_1$'s have recovered their magnetisation in the positive z' axis, those signals will appear upright, while the signals from the carbons with the longer $T_1$ values i.e. those of the initiation and termination groups, will retain magnetisation in the negative z' axis and give inverted signals.

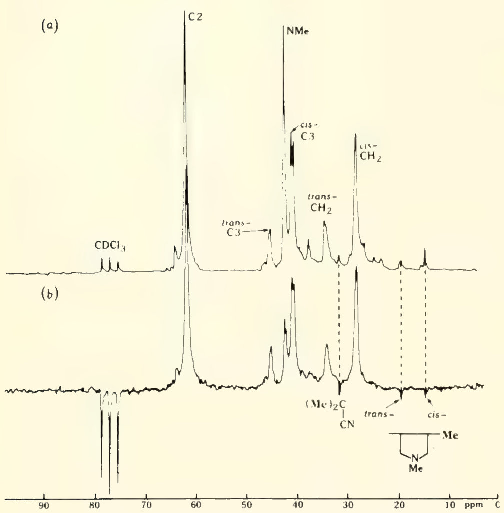



Figure 12. $^{13}$C nmr ($180^0$-t-$90^0$) spectra of cyclopolymer from N-methyl-N,N-diallylamine, t = 20 s.; t = 0.2 s.

A comparison of the spectra of the cyanoisopropyl radical induced cyclopolymer from N-methyl diallylamine (MW ~ 2000, i.e. about 20 units) after t=20 s. and t=0.2 s. (Figures 12a and 12b) shows a number of inverted signals in Figure 12b that can be assigned to carbon atoms of the initiation and termination groups. Specifically, the signal at 31.7 ppm can be assigned to the methyl group of the initiating cyanoisopropyl radical and the signals at 14.6 ppm and 19.3 ppm to *cis* and *trans*-methyl groups of terminating 3-methylpyrrolidine residues. The presence of the C-methyl groups on the terminating pyrrolidine indicates that termination occurs by an abstraction of hydrogen, probably from the solvent. These particular polymers are of low molecular weight but with state-of-the-art spectometers that have greater dynamic range than our own the same approach should be possible with higher molecular weight polymers.

Tacticity Studies

In attempts to determine the sequencing of monomer units (tacticity) in a polymer it has been observed that the chemical shift sensitivity of a particular carbon may depend upon the configuration of from two (dyad) to seven (heptad) monomer units (Randall, 1977). The ensuing nmr signal from such a carbon can therefore consist of as many as thirty-six distinct resonance lines. The analysis of tacticity is important in relating polymer structure to polymer properties but is not easy since line shape analyses are unreliable. An example is the signal from the substituted aromatic carbon of polystyrene (Figure 13) which is obviously make up of a number of closely spaced individual lines.

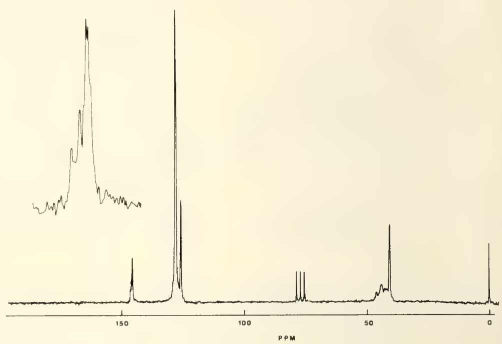



Figure 13. $^{13}$C nmr spectrum of polystyrene (INSERT: Expanded region showing the fully substituted aromatic carbon signal).

I wish to describe a two pulse, inversion/recovery type $(\alpha\text{-}\tau\text{-}\delta\text{-}5T_1)_n$ $^{13}$C nmr sequence which induces different phase and intensity variations in the individual lines within such peaks and which, by varying the value of $\tau$ can produce a set of different peak shapes all of which must fit the same parameter set of chemical shifts and intensities (Johns, 1980).

The sequence (Figure 14) consists of an initial pulse which rotates the equilibrium magnetisation ($M_0$) through an angle ($\alpha$) such that a significant component of the magnetisation exists in the xy plane (we use an angle of $220^0$). The time delay ($\tau$) before the second pulse is set to less than the spin-spin relaxation time ($T_2^*$) so that a magnetisation component remains in the xy plane at the commencement of the second pulse which rotates the magnetisation through a further angle ($\delta$). During the time $\tau$, the xy component of magnetisation precesses about the z' axis and by varying the time $\tau$ a series of spectra can be obtained with phase and intensity variations arising from different excess precession angles. A series of different peak shapes can be experimentally produced.

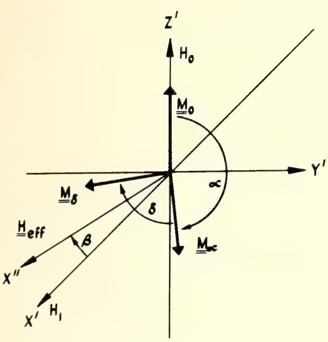



Figure 14. Two Pulse Sequence $(\alpha\text{-}\tau\text{-}\delta\text{-}5T_1)_n$

The spin magnetisation during the two pulse sequence can be described by the following equations:

$$M_\alpha = R_{y'}^{-1}(\beta)\, R_{x''}(\alpha)\, R_{y'}(\beta)\, M_o$$

$$M_\tau = R_{z'}(\Theta)\, \underline{S}\, M_\alpha + (1-e_1^{-t/T_1})\, M_o$$

$$M_\delta = R_y^{-1}(\beta)\, R_{x''}(\delta)\, R_{y'}(\beta)\, M_\tau$$

where $M_\alpha$ and $M_\delta$ are the magnetisations after the α and δ pulses, $M_\tau$ the magnetisation following the time delay τ, $R_{y'}(\beta)$, $R_{x''}(\alpha)$ and $R_{z'}(\Theta)$ are rotation matrices which rotate the magnetisation about the y', x'' and z' axis respectively. The angle Θ is the precession angle of the magnetisation during the time τ about the z' axis and θ is the excess precession angle defined as

$$\Theta = 2n\pi + \theta = (\Omega-\omega_1)\tau$$

where $(\Omega-\omega_1)$ is the offset frequency

S is the relaxation matrix given by

$$S = \begin{bmatrix} e^{-\tau/T_2^*} & 0 & 0 \\ 0 & e^{-\tau/T_2^*} & 0 \\ 0 & 0 & e^{-\tau/T_1} \end{bmatrix}$$

Evaluation of $M_\delta$ gives a system of equations which provides the data necessary to define the spin state after the δ-pulse and these equations have been adapted to a Fortran programme to calculate a theoretical spectrum.

The simulation of a number of different peak shapes, derived from different τ values for a single set of chemical shifts and intensities should confirm the analysis of a multiline resonance peak.

Figs. (15a,b,c) show the experimental $^{13}C$ nmr spectrum of the fully substituted aromatic carbon signal of polystyrene in $CDCl_3$ using a single FT pulse sequence, a $(220^0\text{-}0.2\ s.\text{-}110^0\text{-}5xT_1)_n$ sequence and a $(220^0\text{-}0.35\ s.\text{-}110^0\text{-}5xT_1)_n$ sequence.

Figs. (16a,b,c) show the theoretical $^{13}C$ nmr spectrum of the fully substituted aromatic carbon signal of polystyrene using 22 lines which correspond to the different chemical shifts and a $(220^0\text{-}20.0\ s.\text{-}110^0\text{-}5xT\ )_n$ sequence, a $(220^0\text{-}0.2\ s.\text{-}110^0\text{-}5xT_1)_n$ sequence and a $(220^0\text{-}0.35\ s.\text{-}110^0\text{-}5xT_1)_n$ sequence.

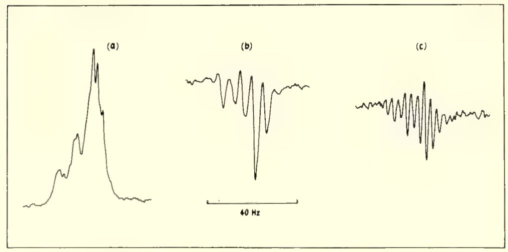



Figure 15. $^{13}C$ nmr spectrum of the fully substituted aromatic carbon signal of polystyrene in $CDCl_3$ using a

(a) Single FT pulse sequence.
(b) $(220^0\text{-}0.2\ s.\text{-}110^0\text{-}5xT_1)_n$ pulse sequence.
(c) $(220^0\text{-}0.35\ s.\text{-}110^0\text{-}5xT_1)_n$ pulse sequence.

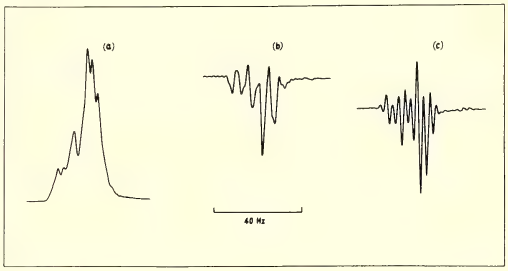



Figure 16. Theoretical $^{13}C$ nmr spectrum of fully substituted aromatic carbon signal of polystyrene using 22 lines and a

(a) $(220^0\text{-}20.0\ s.\text{-}110^0\text{-}5xT_1)_n$ pulse sequence.
(b) $(220^0\text{-}0.2\ s.\text{-}110^0\text{-}5xT_1)_n$ pulse sequence.
(c) $(220^0\text{-}0.35\ s.\text{-}110^0\text{-}5xT_1)_n$ pulse sequence.

The good agreement between the experimental and simulated spectra confirms a heptad sensitivity to chemical shift for the fully substituted aromatic carbon of polystyrene although 14 of the 36 possible lines are coincident in shift within the experimental resolution.

Of course the complete assignment of the tacticity broadened lines in the $^{13}C$ nmr spectrum of polymers will require the analysis of a number of samples prepared under different conditions with different monomer sequences, but the method should

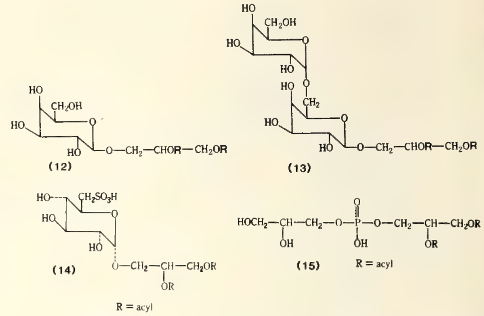
prove an excellent technique for the analysis of such spectra.

Biological Polymers

The $^{13}C$ nmr technique is equally suited to the study of biological polymers. Our own particular interest is in the use of $^{13}C$ nmr as a means of probing the structure and function of biological membranes. A membrane is considered to be made up of a mosaic of globular proteins within a lipid bilayer (Singer, 1972) sometimes described as "icebergs in a lipid sea". The properties of the membrane depend particularly upon the fluidity of the lipid bilayer and the measurement of $^{13}C$ longitudinal relaxation times provides an excellent method for the study of motion within these lipid bilayers.

The particular membrane on which we have focussed our attention is the inner chloroplast membrane of green plants. This is where the light trapping, energy transfer and energy storage of photosynthesis takes place. The chloroplast membrane system, unlike most biological membranes, consists principally of neutral glycolipids rather than the charged phospholipids of other organelle and cellular membranes. The photosynthetic membranes are composed of approximately 50% protein and 50% lipid, the lipid composition comprising the four types; MGG (40%) (12), DGG (40%) (13), SL (10%) (14), and PG (10%) (15). The fatty acid composition of the lipids shows a remarkably high concentration of (9Z,12Z,15Z)-octadeca-9,12,15-trienoic acid (α-linolenic acid) which may comprise over 90% of the acylating acids in DGG and MGG, 50% in SL and up to 30% in PG.

We have isolated and purified these lipids and measurement of their $^{13}C$ nmr spectrum in $d_4$-methanol, e.g. that of DGG (Fig. 17) allows the assignment of all carbons in the molecules. We have measured the $^{13}C$ longitudinal relaxation times




in different solvent systems, calculated the correlation times ($\tau_c$) (Table 1) and interpreted these in terms of different secondary structures in the different solvents (Johns, 1977a). In methanol, correlation times of $2.8 \pm 0.4 \times 10^{-10}$ s. for all the glyceryl and galactosyl carbon atoms of DGG indicate that this portion of the lipid molecule undergoes rotation as a unit. The correlation times of the acyl chain carbon atoms however, decrease along the chain from C2 ($8.0 \times 10^{-11}$ s.) to the terminal methyl carbon ($1.7 \times 10^{-12}$ s.). This increase in motion arises from segmental motion in the acyl chain induced by β-coupled *trans-gauche* rotations about the C-C bonds. The total motion within the chain is derived from a combination of both molecular tumbling and segmental motion.

The longitudinal relaxation times and correlation times of the individual carbon atoms of

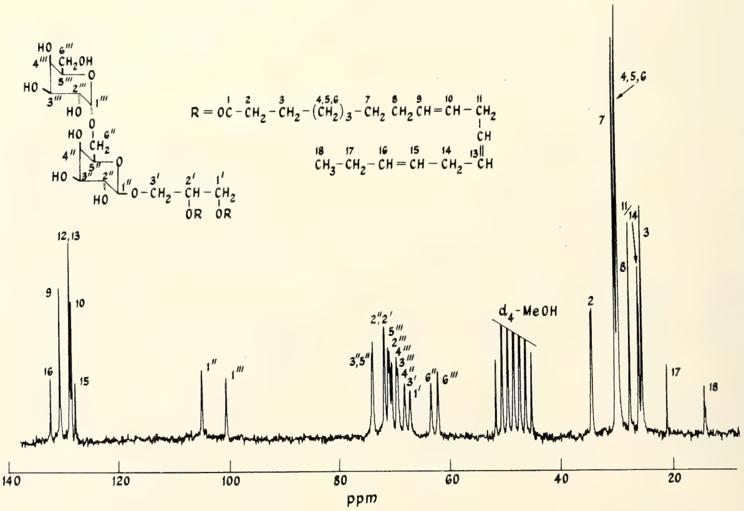



Figure 17. $^{13}C$ nmr of DGG in $d_4$-methanol.

Table 1

$^{13}C$ Longitudinal Relaxation Times (sec) and Correlation Times (x$10^{11}$ sec) in Brackets of DGG in Various Solvents.

| Carbon | $CD_3OD$ | | $CDCl_3$ | | $D_2O$ | |
|---|---|---|---|---|---|---|
| | | | α-Linolenic acid chain | | | |
| 2 | 0.30 | (7.8) | 0.09 | (26) | | |
| | 0.25 | (9.3) | | | | |
| 3 | 0.53 | (4.4) | 0.26 | (9.0) | | |
| 4 | 0.72[a] | (3.2) | 0.47[a] | (5.0) | 0.26[a] | (9.0) |
| 5 | 0.72[a] | (3.2) | 0.47[a] | (5.0) | 0.26[a] | (9.0) |
| 6 | 0.72[a] | (3.2) | 0.47[a] | (5.0) | 0.26[a] | (9.0) |
| 7 | 0.91 | (2.6) | 0.72 | (3.2) | | |
| 8 | 1.5 | (1.6) | 0.84 | (2.8) | | |
| 9 | 2.1 | (1.1) | 1.2 | (1.9) | | |
| 10 | 2.1 | (1.1) | 1.3 | (1.8) | | |
| 11 | 2.9[b] | (0.80) | 2.1 | (1.1) | 0.88[b] | (2.7) |
| 12 | 3.9 | (0.60) | 2.6 | (0.90) | 0.83 | (5.6) |
| 13 | 3.9 | (0.60) | 2.6 | (0.90) | 0.83 | (5.6) |
| 14 | 2.9[b] | (0.80) | 3.0 | (0.78) | 0.88[b] | (2.7) |
| 15 | 7.6 | (0.31) | 7.1 | (0.33) | 2.3 | (2.0) |
| 16 | 7.4 | (0.32) | 6.9 | (0.34) | 2.3 | (2.0) |
| 17 | 11.1 | (0.21) | 9.5 | (0.25) | 3.0 | (0.78) |
| 18 | 8.9 | (0.17) | 7.8 | (0.20) | 3.6 | (0.43) |
| | | | Glycerol chain | | | |
| 1 | 0.10 | (24) | 0.03[c] | (100) | 0.08[d] | (30) |
| 2 | 0.16 | (30) | | | | |
| 3 | 0.10 | (24) | | | | |
| | | | Galactoside groups | | | |
| 1' | 0.16 | (30) | 0.035 | (800) | | |
| 2' | 0.16 | (30) | | | | |
| 3' | 0.15 | (32) | 0.035 | (800) | | |
| 4' | 0.12 | (40) | | | | |
| 5' | 0.15 | (32) | 0.035 | (800) | | |
| 6' | 0.07 | (32) | | | 0.06 | (100) |
| 1" | 0.19 | (25) | 0.035 | (800) | | |
| 2" | 0.17 | (28) | 0.04[d] | (200) | | |
| 3" | 0.14 | (34) | 0.04[d] | (200) | | |
| 4" | 0.18 | (26) | 0.04[d] | (200) | | |
| 5" | 0.17 | (28) | 0.04[d] | (200) | | |
| 6" | 0.19 | (12) | 0.03[c] | (100) | 0.08[d] | (30) |

[a,b,c,d] Averaged values obtained from unresolved signals.

the galactosyl and glyceryl moieties of DGG in chloroform are an order of magnitude different from the values in methanol. In chloroform, the motion of the carbon atoms in the polar regions of the molecules are severely restricted which indicates that the hydrophilic groups are associated and that the most likely secondary structure of the lipid molecule is one of an inverted micelle. The molecular tumbling of such a polymeric inverted micelle would be extremely slow which is consistent with the short relaxation times. By contrast, the motion of the acyl chain carbon atoms, which increase from C2 to the terminal methyl group carbons, are only slightly less than those of the monomeric form. Segmental motion along the acyl chain can again account for the observed values.

The correlation times of the glyceryl and galactosyl carbons of DGG in water correspond to a packing of the sugar moieties but in a structure in which the motion of the atoms is greater than in the inverted micellar structure. This is reflected in the broadened spectra of DGG in water (Figure 18). The relaxation times of the acyl chain carbons reveal a more restricted motion than observed in the inverted micelles but once again segmental motion increases from the carbon atoms adjacent to the polar groups in the terminal methyl group carbons. The dynamic properties of the individual carbon atoms of DGG in water are therefore consistent with a bilayer structure with associated head groups at the water interface and a hydrophobic inner region comprised of acyl chains. Unlike the galactosyl lipids, SL is characterised by the presence of almost equimolar amounts of palmitic and α-linolenic acids. Comparison of the longitudinal relaxation times of the carbon atoms in the two chains (Table 2) (Johns, 1978) shows that at all equivalent positions that can be resolved (Figure 19) the motion of the α-linolenic acid chain is greater than that in the palmitic acid chain, but less than that of the same acid in DGG which contains two α-linolenic acid molecules.

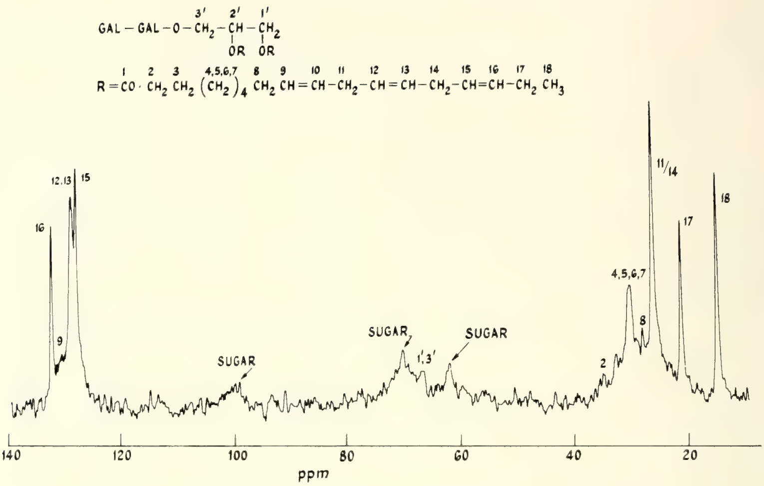


Figure 18. $^{13}C$ nmr of DGG in $D_2O$

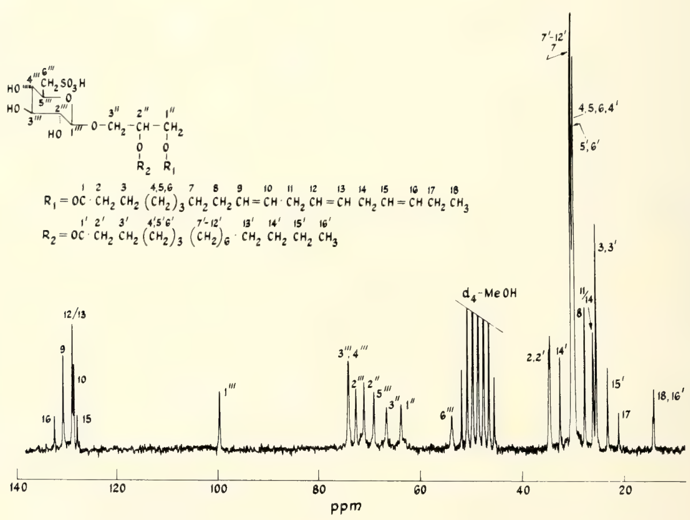


Figure 19. $^{13}C$ nmr of SL in $d_4$-methanol

The presence of the saturated acyl chain in SL obviously restricts motion in the unsaturated acyl chain to a greater extent than does a second unsaturated chain.

This result indicates that the $^{13}C$ nmr technique can distinguish different motions in carbon atoms which are at the same distance from the polar head group in the different acyl chains of a lipid molecule, unlike the ESR spin label technique which only measures the motion of a reporter molecule.

We are using vesicles prepared from DGG in water and vesicles prepared from the total chloroplast membrane lipids in water to study the effect of added components such as antibiotics, anaesthetics, proteins and peptides to the lipid bilayers. The polyene antibiotic, amphotericin B, has been shown to inhibit a number of membrane-associated reactions in higher plant chloroplasts. That the inhibitions result from effects on

Table 2

$^{13}$C Longitudinal Relaxation Times (sec) and Correlation Times (x10$^{11}$ sec) in Brackets of SL in Various Solvents.

| Carbon | $CDCl_3$ | | $CD_3OD$ | | $D_2O$ | | $CDCl_3$ | | $CD_3OD$ | | $D_2O$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | α-Linolenic acid chain | | | | | | Palmitic acid chain | | | | | |
| 2 | 0.14[a] | (16.7) | 0.29[a] | (8.0) | 0.2[a] | (11.6) | 0.14[a] | (16.7) | 0.29[a] | (8.0) | 0.2[a] | (11.6) |
| 3 | 0.30[b] | (7.8) | 0.44[b] | (5.3) | | | 0.30[b] | (7.8) | 0.44[b] | (5.3) | | |
| 4 | 0.53[c] | (4.4) | 0.67[c] | (3.5) | 0.3[c] | (7.8) | 0.53[c] | (4.4) | 0.67[c] | (3.5) | 0.3[c] | (7.8) |
| 5 | 0.53[c] | (4.4) | 0.67[c] | (3.5) | 0.3[c] | (7.8) | 0.63[d] | (3.7) | 0.71[d] | (3.3) | 0.3[c] | (7.8) |
| 6 | 0.53[c] | (4.4) | 0.67[c] | (3.5) | 0.3[c] | (7.8) | 0.63[d] | (3.7) | 0.71[d] | (3.3) | 0.3[c] | (7.8) |
| 7 | 0.77[e] | (3.0) | 0.86[e] | (2.7) | | | 0.77[e] | (3.0) | 0.86[d] | (2.7) | 0.3[c] | (7.8) |
| 8 | 0.87 | (2.7) | 1.0 | (2.3) | 0.3 | (7.8) | 0.77[e] | (3.0) | 0.86[e] | (2.7) | 0.3[c] | (7.8) |
| 9 | 1.2 | (3.5) | 1.2 | (3.5) | | | 0.77[e] | (3.0) | 0.86[e] | (2.7) | 0.3[c] | (7.8) |
| 10 | 1.2 | (3.5) | 1.2 | (3.5) | | | 0.77[e] | (3.0) | 0.86[e] | (2.7) | 0.3[c] | (7.8) |
| 11 | 1.9[f] | (1.2) | 2.6[f] | (0.90) | 0.8[f] | (2.9) | 0.77[e] | (3.0) | 0.86[e] | (2.7) | 0.3[c] | (7.8) |
| 12 | 2.4 | (1.7) | 2.8 | (1.5) | 0.6 | (7.0) | 0.77[e] | (3.0) | 0.86[e] | (2.7) | 0.3[c] | (7.8) |
| 13 | 2.4 | (1.7) | 2.8 | (1.5) | 0.6 | (7.0) | 0.63[d] | (3.7) | 0.71[d] | (3.3) | 0.3[c] | (7.8) |
| 14 | 1.9[f] | (1.2) | 2.6[f] | (0.90) | 0.8[f] | (2.9) | 2.4 | (0.97) | 2.5 | (0.93) | 0.6 | (3.9) |
| 15 | 3.6 | (1.2) | 4.6 | (0.91) | 1.0 | (4.2) | 3.0 | (0.78) | 3.0 | (0.78) | 0.8 | (2.9) |
| 16 | 3.6 | (1.2) | 4.6 | (0.91) | 1.0 | (4.2) | 3.6 | (0.43) | 6.5[g] | (0.24) | 2.0[g] | (0.78) |
| 17 | 6.0 | (0.39) | 9.7 | (0.24) | 2.1 | (1.1) | | | | | | |
| 18 | 5.7 | (0.27) | 6.5[g] | (0.24) | 2.0[g] | (0.78) | | | | | | |
| | Glycerol chain[h] | | | | | | Sulphoquinovosyl group[h] | | | | | |
| 1 | 0.03 | (2500) | 0.07 | (34) | | | 0.06 | (2500) | 0.14 | (34) | 0.05 | (130) |
| 2 | 0.06 | (2500) | 0.13 | (37) | 0.05 | (130) | 0.05 | (2000) | 0.14 | (34) | 0.05 | (130) |
| 3 | 0.03 | (2500) | 0.07 | (34) | | | 0.05 | (2000) | 0.13 | (37) | 0.04 | (200) |
| 4 | | | | | | | 0.04 | (1400) | 0.13 | (37) | 0.05 | (130) |
| 5 | | | | | | | 0.04 | (1400) | 0.13 | (37) | | |
| 6 | | | | | | | 0.03 | (2500) | 0.08 | (30) | 0.03 | (600) |

[a-g] Averaged values obtained from unresolved signals.

[h] Correlation times in $CDCl_3$ are approximate.

membrane fluidity is clearly indicated by the relaxation time changes on addition of the antibiotic. (Table 3) (Bishop, 1978). The results indicate that the presence of the antibiotic causes a significant restriction in motion of the acyl chain carbons which is consistent with the occurrence of intercalation of the antibiotic between the acyl chains. Conversely, the addition of chloroform to the vesicles results in an increase in motion in the acyl chains.

Table 3

Effect of Amphotericin B on the Motion of Acyl Chains of Aqueous Multibilayers of DGG

| Carbon Atom | Longitudinal relaxatiom time (sec) | |
|---|---|---|
| | DGG | DGG plus Amphotericin B (10%) |
| 4/5/6 | 0.26 | 0.27 |
| 11/14 | 0.88 | 0.91 |
| 12/13 | 0.83 | 0.91 |
| 15 | 2.3 | 1.2 |
| 16 | 2.3 | 1.4 |
| 17 | 3.0 | 2.5 |
| 18 | 3.6 | 2.7 |

Continuing experimentation on peptides and proteins, specifically membrane associated proteins such as the photosynthetic protein of the chloroplast, should lead to conclusive results on the interaction of proteins and lipids. These will be of importance in a variety of fields ranging from the mechanism of aging to the fundamental processes of colour vision and photosynthesis.

Future

$^{13}$C nmr and other magnetic resonance techniques promise an exciting future for study in the synthetic and the biological polymer fields. The examples given have been restricted to $^{13}$C solution spectroscopy, however, current technological development of instrumentation is such that deuterium and phosphorous nmr now offer great potential in the biological/medical fields and the use of solid state nmr techniques offers unlimited opportunities. I trust that this short overview of our own work in the nmr of polymers might inspire you to use the technique in your own studies and apply the techniques in new areas of research.

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# Stratigraphic Palynology From Shallow Bores in the Namoi River and Gwydir River Valleys, North-Central New South Wales

HELENE A. MARTIN

ABSTRACT. The palynology of over fifty bores drilled into the Cainozoic sediments covering the Coonamble Embayment, Broomi Trough and Lightning Ridge Shelf of the Surat Basin are reported here. The Early Cretaceous bedrock is either the *Dictyotosporites speciosus* Zone or less frequently, the *Crybelosporites stylosus* Zone, and is encountered everywhere. The Cainozoic alluvial sediments are: (1) the mid-late Miocene *Triporopollenites bellus* Zone which has a patchy distribution throughout the area. It is restricted to the deeper, consistently grey clays, and in some bores, directly overlies the Early Cretaceous bedrock: (2) Pliocene-Pleistocene assemblages found only near Narrabri and (3) Pleistocene assemblages near Moree.

Tertiary deposition on the Early Cretaceous landscape started in the mid-late Miocene. The vegetation must have been a floristically rich closed forest, and the rainfall at least 150cm per annum. There was a subsequent decrease in rainfall. The Pliocene-Pleistocene floras are less diverse, but there were still substantial areas of closed forest. The Pleistocene floras represent open woodland with a well developed herbaceous ground cover.

## INTRODUCTION

The Water Resources Commission of New South Wales has sunk many bores in the Namoi and Gwydir River Valleys in its program of exploration for underground water. This paper presents the palynological results for the area from Narrabri to Burren Junction of the Namoi River Valley, and to the north, the Moree district of the Gwydir River Valley. Over fifty bores have yielded workable assemblages.

The study area is located on the eastern edge of the Great Australian Basin. The Early Cretaceous, regarded as bedrock in water exploration, is covered by Cainozoic sediments. As most bores penetrate both the Cainozoic and Early Cretaceous, the palynology of both is included here. The bores just east of Narrabri mark the eastern-most occurrence of the Early Cretaceous bedrock along the Namoi River. Further upstream, the bedrock is Permian.

## GEOLOGY

Most of the area of this study is situated on the eastern edge of the Coonamble Embayment, one of the structural units of the Great Australian Basin, although the Moree district is in the Surat Basin proper. The uppermost member encountered here is probably equivalent to the Early Cretaceous Bungil Formation, although the overlying Wallumbilla Formation, may be included as well (Hawke *et al.* 1975). The entire area is overlain by Cainozoic and alluvial sediments.

The locations of bores are shown in Fig. 1. The upper part of the bore logs show red, brown, yellow and orange coloured sediments, often with a greyish tint or with thin bands of pale grey. Occasionally the sediments are mottled (e.g. Bore 36017 of the Gwydir Valley). The lower part of the logs show consistently grey sediments. Bedrock is either shale or sandstone.

The sediments are predominantly clays to the west, especially in the Burren Junction area and Merah North. They are mainly sands and gravels to the east, e.g. around Narrabri. Selected bore logs are shown in Fig. 2. The boundary between the Cainozoic and Early Cretaceous sediments is difficult to detect on lithologic evidence alone.

Only the consistently grey sediments are useful for palynology. However, bands of only one or two metres thicknesses of grey clay may be found within the predominantly red-brown-yellow sediments, and these bands have yielded pollen. Sands and gravels are usually not suitable for palynology, but they may contain thin bands of clay also. In this study, the upper part of the sediments which are predomonantly red-brown-yellow in colour have rarely yielded pollen, and most of the assemblages reported here came from the lower, consistently grey sediments.

## PALYNOSTRATIGRAPHY

Three ages are relevant here, viz the Early Cretaceous, mid-late Miocene and Pliocene-Pleistocene.

(1) Early Cretaceous. Dettmann and Playford (1969) have described a series of Cretaceous palynological zones. Only the two oldest are relevant here, viz the *Crybelosporites stylosus* Zone (earlier part of the Neocomian) and the *Dictyotosporites speciosus* Zone (Neocomian to almost the end of the Aptian).

These two zones are distinguished by a small group of diagnostic species, but the general quantitative characteristics of the two are very similar. Should the diagnostic species be absent, then it is not possible to distinguish the two zones apart. All of the assemblages recorded here would fit these two zones on the general characteristics, but the diagnostic species are not present in many of them. In some cases their absence may result from poor preservation but in others it appears to be simply a chance absence. Where it is not possible to place an assemblage in one of the zones, it is recorded as Early Cretaceous.

(2) Mid-late Miocene. The Tertiary assemblages all fit the *Triporopollenites bellus* Zone described by Stover and Partridge (1973). *Haloragacidites haloragoides* has not been found and this indicates the earlier part of the zone rather than the later

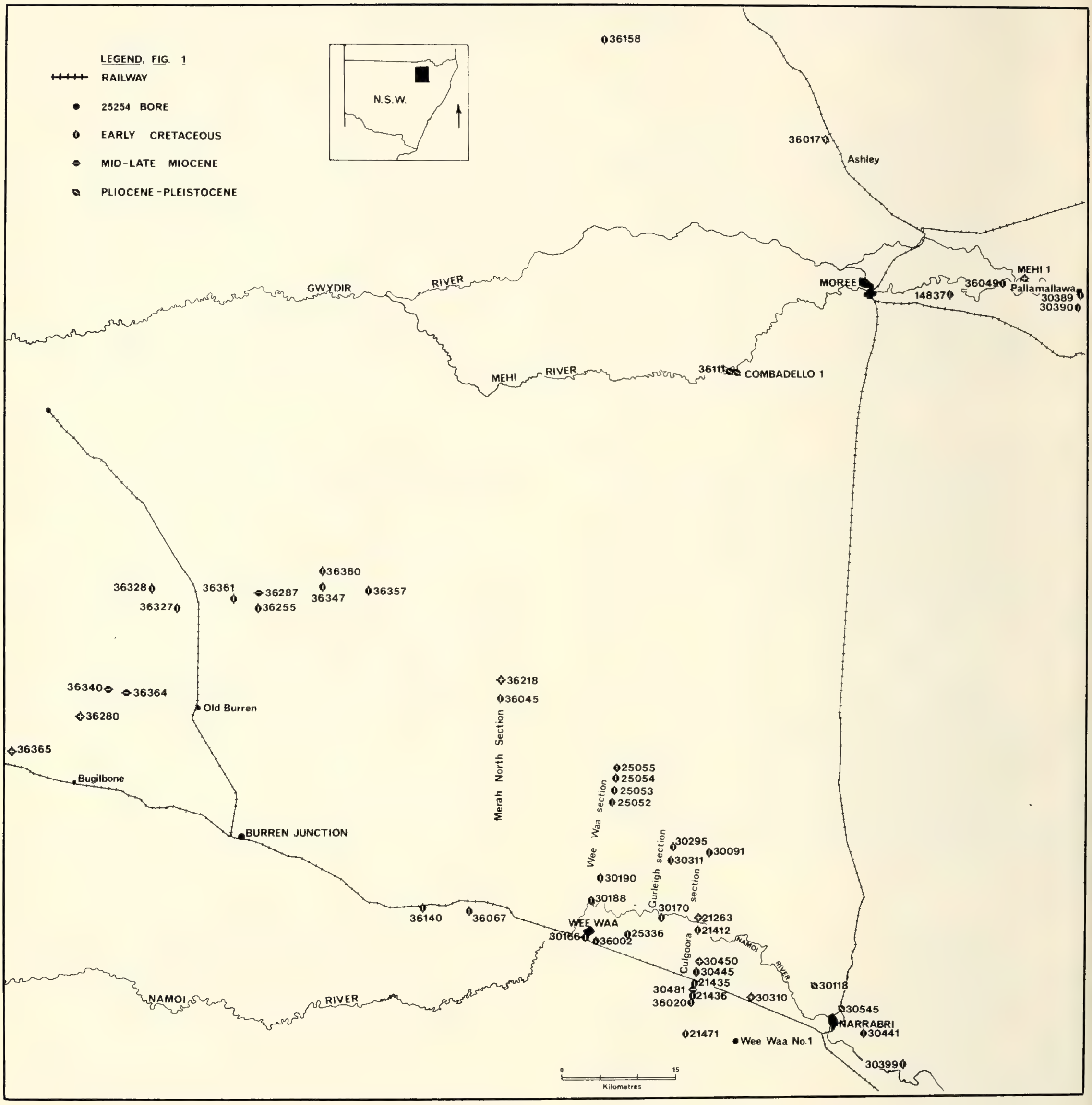


Fig. 1 The locations of bores and the distribution of the palynological ages.

part. If there is insufficient evidence to place an assemblage in the *T. bellus* Zone, then it is recorded as mid-Tertiary. However, there is no evidence to indicate that such assemblages are not equivalent to the *T. bellus* Zone.

(3) Pliocene-Pleistocene. Two types of assemblages are recognised here: one with a very high Compositae and Gramineae content which is clearly Pleistocene and the other, with a lower content of these two taxa and more diversity. The latter is considered to be about the Pliocene-Pleistocene boundary. The distinction of the Pliocene and Pleistocene is based on the abundance of Compositae, Gramineae, and other herbaceous taxa, and is discussed in Martin, 1979.

The occurrences of these palynological zones and ages is listed in Tables 1 and 2. Fig. 1 shows their distribution and the species composition of selected assemblages is given in the Appendix.

DISCUSSION

The Early Cretaceous basement is encountered everywhere. In the Namoi Valley, it is usually

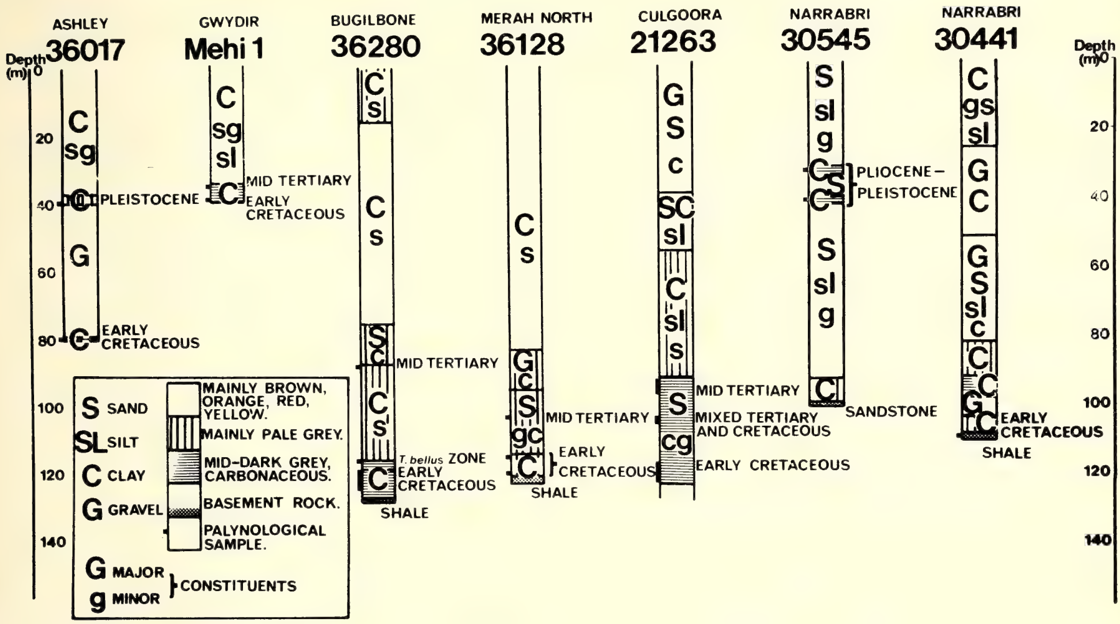


Fig. 2 Selected bores showing the logs and palynological zones.

found below 90 m, but there are a few occurrences above this level, the shallowest being 59 m. The shallow bedrock is found near the edge of the Cainozoic valley. In the Gwydir Valley, basement is not so deep, at 34 m to 80 m. Most of the assemblages which can be assigned to a palynological zone can be placed in the *Dictyotosporites speciosus* Zone and only a few are assigned to the older *Crybelosporites stylosus* Zone. As the older assemblage is found in the deeper parts of the Cainozoic Valley, it probably represents the Mooga Sandstone which underlies the Bungil Formation. Cretaceous formations have been reported from several bores further north of Moree. The evidence presented here suggests that the upper part of the Jurassic Orallo Formation recorded in the petroleum well Wee Waa No. 1 (Hawke *et al.* 1975 and Bourke and Hawke, 1977) should be referred to the Cretaceous. The Cretaceous occurs also in other bores outside of the area reported here.

The Tertiary assemblages are all mid-late Miocene in age and have a patchy distribution. There is only one record from the Gwydir Valley and relatively few from the Namoi Valley. These assemblages are all found in the deeper parts of the bores, in the consistently grey clays. In some bores, the mid-late Miocene sediments directly overly the Early Cretaceous basement.

There are only two records of Pliocene-Pleistocene assemblages near Narrabri and three of Pleistocene age in the Gwydir Valley. All of the assemblages are found in the narrow grey clay bands located above the predominantly grey sediments.

Taylor (1978, Fig. 2) shows Eocene deposition in his cross section through Walgett and Narrabri. His evidence is based on an unpublished report (Martin, 1973) in which one poor assemblage, the only Tertiary assemblage known from the whole of this area at the time, was tentatively thought to be within the range of Eocene to Miocene. This assessment was made before the precise zonation of Stover and Partridge (1973) was available. Reassessment of this assemblage shows very clearly that it is mid-late Miocene in age, and not Eocene. No Eocene assemblages have been encountered anywhere in this region.

Tertiary deposition started in mid-late Miocene time, on the Early Cretaceous landscape. In favourable topographic locations, swamps, small lakes, abandoned river courses etc., provided the permanently wet environments necessary for pollen preservation. This mid-late Miocene landscape was clothed in closed forests which were quite rich, floristically. As *Nothofagus* is an abundant pollen producer, the percentages here indicate that it was only a minor component of the forests, possibly restricted to certain localities, e.g. the highlands (Martin, 1978). The percentages of Myrtaceae indicate that this family was probably well represented. However, the best indication of the richness of the flora is seen in the unidentified pollen types with up to 20 types of unknown botanical affinities accounting for up to 40% of the pollen count. Closed forest is only found today east of the Divide and about ten taxa in these mid-late Miocene floras are still found in the coastal regions of southern Queensland and northern New South Wales. Judging from the requirements of closed forests today, the

rainfall must have been at least 150 cm per annum, with a relatively high humidity maintained throughout the year (Baur, 1957).

Conditions were unsuitable for pollen preservation during the Pliocene. The landscape lacked the permanently wet swamps etc. No doubt there was a decrease in rainfall, but a strongly seasonal climate with a marked drought period would also contribute to these unfavourable conditions for pollen preservation. At the very end of the Pliocene and into the Pleistocene, there were a few permanently wet environments. At this time the floras were less diverse than those of the mid-late Miocene, but there was still substantial areas of closed forests. Araucariaceae (most Likely *Araucaria*) was probably conspicuous in these forests. The diversity of the Pleistocene floras was very restricted. At this time, there was an open woodland or trees were restricted to small areas, with a well developed herbaceous ground cover in which Compositae was a conspicuous element.

TABLE 1
GWYDIR RIVER VALLEY
THE OCCURRENCE OF THE PALYNOLOGICAL ZONES

Bores arranged E → W then N → S

| Bore | Depth (m) | Palynological Zone or Age |
|---|---|---|
| 36158 | 49.5-53 | Early Cretaceous |
| 36111 | 5.6-7.6 | Pleistocene |
| Combadello 1 | 7.6 | *Possible Pleistocene |
| 36017 | 38.1-39.6 | Pleistocene |
| | 78.2-80 | Early Cretaceous |
| 14837 | 56.1-61 | *Dictyotosporites speciosus* Zone |
| 36049 | 35.5 m | *D. speciosus* Zone |
| Mehi 1 | 35.8 | Mid Tertiary |
| | 39.1 | Early Cretaceous |
| 30389 | 48 | *D. speciosus* Zone |
| 30390 | 34.5 | Early Cretaceous |

* A very poor assemblage

TABLE 2
NAMOI RIVER VALLEY
THE OCCURRENCE OF THE PALYNOLOGICAL ZONES

Bores arranged E → W then N → S

| Bore | Depth (m) | Palynological Zone or Age |
|---|---|---|
| BURREN JUNCTION AREA | | |
| 36365 | 86-88 | *T. bellus* Zone |
| | 98-99.8 | *T. bellus* Zone |
| | 118.4-125 | *Dictyotosporites speciosus* Zone |
| 36280 | 87.6-88.9 | Mid Tertiary |
| | 116.2 | *T. bellus* Zone |
| | 118-127 | Early Cretaceous |
| 36340 | 87-87.5 | *T. bellus* Zone |
| 36364 | 113.5-114.5 | *T. bellus* Zone |
| | 119-125 | *T. bellus* Zone |
| 36328 | 103.6-105.1 | *D. speciosus* Zone |
| | 108.5 | *D. speciosus* Zone |
| 36327 | 100.6 m | Early Cretaceous |
| 36361 | 121.9-123.4 | Early Cretaceous |
| | 126.5 | *D. speciosus* Zone |

TABLE 2 (Cont.)

| Bore | Depth (m) | Palynological Zone or Age |
|---|---|---|
| 36287 | 111.2-115.8 | *T. bellus* Zone |
| 36255 | 121.9-123.7 | Early Cretaceous |
| 36360 | 121.0 | *D. speciosus* Zone |
| 36347 | 115.8 | *D. speciosus* Zone |
| 36357 | 129.5 | *D. speciosus* Zone |
| MERAH NORTH SECTION | | |
| 36128 | 102.1-103.6 | Mid Tertiary |
| | 114.3-115.8 | *D. speciosus* Zone |
| | 118.9-120.4 | *D. speciosus* Zone |
| 36045 | 118.9-121.9 | *D. speciosus* Zone |
| 36140 | 71.6-73.4 | *D. speciosus* Zone |
| 36067 | 63-67 | Early Cretaceous |
| WEE WAA SECTION | | |
| 25055 | 95.4 | *C. stylosus* Zone |
| 25054 | 93-93.3 | Early Cretaceous |
| 25053 | 93-93.3 | Early Cretaceous |
| 25052 | 64.9-68.6 | *D. speciosus* Zone |
| 30190 | 106.1 | *C. stylosus* Zone |
| 30188 | 110.3 | Early Cretaceous |
| 30166 | 91.4 | *C. stylosus* Zone |
| 36002 | 89.9-91.4 | Early Cretaceous |
| GURLEIGH SECTION | | |
| 30295 | 105.1-109.1 | Early Cretaceous |
| 30311 | 136.7 | Early Cretaceous |
| 30170 | 107.6-107.9 | Early Cretaceous |
| 25336 | 103.6-105.1 | Early Cretaceous |
| CULGOORA SECTION | | |
| 30091 | 59.4-62 | Early Cretaceous |
| | 78.9-79.2 | Early Cretaceous |
| | 111.2-112.8 | Early Cretaceous |
| 21263 | 92-98.4 | Mid Tertiary |
| | 103-107.3 | Mixed Tertiary and Cretaceous |
| | 114-123.7 | Early Cretaceous |
| 21412 | 136.5 | Early Cretaceous |
| 36019 | 108.2 | Early Cretaceous |
| 30450 | 97-98 | *T. bellus* Zone |
| | 112.8 | Early Cretaceous |
| | 114.0 | Early Cretaceous |
| 30445 | 117.3-118.9 | Early Cretaceous |
| | 124.7-125 | Early Cretaceous |
| 21435 | 118.9-135.9 | Early Cretaceous |
| 30481 | 88.4-90 | Mid Tertiary |
| 21436 | 95.7-108.5 | Early Cretaceous |
| 36020 | 91.4-93 | Early Cretaceous |
| 21471 | 103.6 | Early Cretaceous |
| NARRABRI AREA | | |
| 30310 | 92.9-93.6 | *T. bellus* Zone |
| | 116.7-117 | Early Cretaceous |
| 30118 | 32.3-33.5 | Plio-Pleistocene |
| | 41.1-42.7 | Plio-Pleistocene |
| 30545 | 30.2-32.9 | Plio-Pleistocene |
| | 39.6-40.2 | Plio-Pleistocene |
| 30441 | 109-111 | Early Cretaceous |
| 30399 | 115.8-116 | Early Cretaceous |

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APPENDIX

A PLEISTOCENE ASSEMBLAGE

Bore 36017, 38.1-39.6 m, Gwydir Valley

| Spores | % |
|---|---|
| *Cingulatisporites bifurcatus* (Couper) Martin 1973 | 2 |
| *Deltoidospora inconspicua* Martin 1973 | 1 |
| cf. *Matonisporites ornamentalis* (Cookson) Partridge 1973 | 1 |
| *Reticulatisporites cowrensis* Martin 1973 | 1 |
| *R. echinatus* Martin 1973 | 1 |
| Gymnosperm pollen | |
| *Araucariacites australis* Cookson 1947 | 4 |
| Cupressaceae | 1 |
| *Podocarpus elliptica* (Cookson) Martin 1973 | 1 |
| Angiosperm Pollen | |
| *Casuarina* (*Haloragacidites harrisii* (Couper) Harris 1971 plus *Casuarinidites cainozoicus* Cookson & Pike 1954) | 8 |
| Cyperaceae | 3 |
| *Graminidites media* Cookson 1947 (Gramineae) | 5 |
| *Haloragis haloragoides* (Cookson & Pike) Martin 1973 | 4 |
| Myrtaceae, sp. indet. | 6 |
| *Myrtaceidites eucalyptoides* Cookson & Pike 1954 | 8 |
| *Polyporina chenopodiaceoides* Martin 1973 | 4 |
| *Tubulifloridites* spp. (Compositae) | 44 |
| Four unknown pollen types | 6 |

A PLIOCENE-PLEISTOCENE ASSEMBLAGE

Bore 30545, 30.2-32.9 m, Namoi Valley

| Spores | % |
|---|---|
| *Cingulatisporites bifurcatus* (Couper) Martin 1973 | 0.8 |
| *Cyathea paleospora* Martin 1973 | 3.3 |
| *Deltoidospora inconspicua* Martin 1973 | 0.8 |
| *Laevigatosporites ovatus* Wilson & Webster 1946 | 0.8 |
| cf. *Rouseisporites* sp. | + |
| Gymnosperm pollen | |
| *Araucariacites australis* Cookson 1947 | 22.3 |
| Cupressaceae | 3.3 |
| *Podocarpus elliptica* (Cookson) Martin 1973 | 2.5 |
| Angiosperm pollen | |
| *Acacia myriosporites* Cookson 1954 | 2.5 |
| *Canthiumidites* sp. | + |
| *Casuarina* (*Haloragacidites harrissii* (Couper) Harris 1971 plus *Casuarinidites cainozoicus* Cookson & Pike 1954) | 15.7 |
| *Cupanieidites orthoteichus* Cookson & Pike 1954 | 0.8 |
| Cyperaceae | 3.3 |
| *Graminidites media* Cookson 1947 (Gramineae) | 7.4 |
| Myrtaceae, sp. indet | 5.7 |
| *Myrtaceidites eucalyptoides* Cookson & Pike 1954 | 3.3 |
| *M. mesonesus* Cookson & Pike 1954 | 0.8 |
| *M. parvus* Cookson & Pike 1954 | 1.6 |
| *Polyporina granulata* Martin 1973 | 1.6 |
| cf. *Proteacidites callosus* Cookson 1950 | 0.8 |
| cf. *Tricolpites geranioides* Couper 1960 | 0.8 |
| *Triporopollenitis bellus* Partridge 1973 | 0.8 |
| *Tubulifloridites* spp. (Compositae) | 7.4 |
| 6 unknown pollen types | 13.2 |

MID-LATE MIOCENE ASSEMBLAGES

Bores 36364 and 30450, Namoi Valley

| % of total count | Bore and Depth (m) 36364 113.5-114.5 | 36364 119-125 | 30450 97-98 m |
|---|---|---|---|
| Spores | | | |
| *Baculatisporites disconformis* Stover 1973 | 0.8 | | 2.1 |
| *Cingulatisporites bifurcatus* (Couper) Martin 1973 | 0.8 | | + |
| cf. *C. ornatus* Martin 1973 | | | 0.7 |
| *Cyathea paleospora* Martin 1973 | 4.0 | 4.7 | 2.1 |
| *Cyathidites subtilis* Partridge 1973 | 1.6 | 3.8 | 2.8 |
| *Deltoidospora granulomargo* Martin 1973 | | | 0.7 |
| *D. inconspicua* Martin 1973 | | 0.9 | 2.8 |
| *Gleichenia circinidites* Cookson 1953 | 2.4 | | 0.7 |
| *Klukisporites lachlanensis* Martin 1973 | 0.8 | + | |
| *Laevigatosporites ovatus* Wilson & Webster 1946 | 3.2 | 3.8 | 3.5 |
| *Matonisporites ornamentalis* (Cookson) Partridge 1973 | 0.8 | 0.9 | 0.7 |
| Osmundaceae sp. 2 in Martin 1973 | | 0.9 | |
| *Peromonoletes* sp. | | | 0.7 |
| *Polypodiidites* sp. | | + | 2.4 |
| *Rugulatisporites mallatus* Stover 1973 | | | + |
| *Verrucosisporites kopukuensis* (Couper) Stover 1973 | 0.8 | | |
| Gymnosperm pollen | | | |
| *Araucariacites australis* Cookson 1974 | 1.6 | 1.9 | 2.1 |
| *Dacrydium florinii* (Cookson & Pike) Cookson 1956 | 4.0 | 2.8 | 1.4 |
| *Phyllocladidites palaeogenicus* Cookson & Pike 1954 | 1.6 | 0.9 | 0.7 |
| *Podocarpus australiensis* (Cookson & Pike) Martin 1973 | | 1.9 | 0.7 |
| *P. elliptica* (Cookson) Martin 1973 | 4.0 | 1.9 | 4.2 |
| Angiosperm pollen | | | |
| *Amylotheca* | | | 0.7 |
| *Casuarina* (*Haloragacidites harrisii* (Couper) Harris 1971 plus *Casuarinidites cainozoicus* Cookson & Pike 1954) | 2.4 | 1.9 | 10.2 |
| *Cupanieidites orthoteichus* Cookson & Pike 1954 | 0.8 | | |
| *Drimys tetradites* Martin 1973 | | | 1.4 |
| *Ericipites scabratus* Harris 1965 | | | 0.7 |
| *Graminidites media* Cookson 1947 (Gramineae) | | 0.9 | + |
| Loranthaceae | | 0.9 | |
| *Malvacipollis subtilis* Stover 1973 | | | 2.8 |
| *Milfordia hypolaenoides* Erdtman 1960 | | 0.9 | |
| *Myriophyllum* | | | 0.7 |
| Myrtaceae indet | 5.6 | | 6.4 |
| *Myrtaceidites eucalyptoides* Cookson & Pike 1954 | 7.2 | 4.7 | 2.1 |
| *M. mesonesus* Cookson & Pike 1954 | 1.6 | 4.7 | 0.7 |
| *M. parvus* Cookson & Pike 1954 | 10.5 | 5.7 | 10.6 |
| *M. rhodamnoides* Martin 1973 | | | 0.7 |
| *Nothofagus aspera* Cookson 1959 | 4.0 | 7.5 | 3.5 |
| *N. brachyspinulosa* Cookson 1959 | | | 0.7 |
| *N. emarcida* Cookson 1959 | 7.2 | 17.0 | 9.9 |
| *N. falcata* Cookson 1959 | | 1.9 | |
| *Proteacidites invahoensis* Martin 1973 | 0.8 | 0.9 | 0.7 |
| *P. psuedomoides* Stover 1973 | | 0.9 | |
| *P. subscabratus* Couper 1960 | 0.8 | 1.9 | 2.8 |
| *P. symphonemoides* Cookson 1950 | | | 0.7 |
| *Quintinia psilatispora* Martin 1973 | 0.8 | 0.9 | |
| *Tricolpites psilatus* Martin 1973 | | | 0.7 |
| *Tricolporites leuros* Partridge 1973 | | | 0.7 |
| *T. microreticulatus* Harris 1965 | | | 0.7 |
| *T. sphaerica* Cookson 1947 | | + | |
| *Triporopollenites endobalteus* McIntyre 1965 | 10.5 | 4.7 | 4.2 |
| *T. substriatus* Martin 1973 | | 0.9 | |
| *Triorites minisculus* McIntyre 1965 | 0.8 | | |
| *Triporopollenites bellus* Partridge 1973 | 0.8 | | 0.7 |
| *Tubulifloridites* sp. (Compositae) | | | 0.7 |
| Number of unknown pollen types | 3 | 2 | 14 |
| Percentage of unknown pollen types | 18.5 | 18.9 | 37.6 |

LOWER CRETACEOUS ASSEMBLAGES

| | Bore and Depth (m) | | |
|---|---|---|---|
| | 36328 | 30166 | 30441 |
| | 103.6-108.5 | 91.4 | 109-111 |
| Gymnosperm pollen | | | |
| *Alisporites grandis* (Cookson) Dettmann 1963 | + | + | |
| *A. similis* (Balme) Dettmann 1963 | + | + | |
| *Araucariacites australis* Cookson 1947 | + | | + |
| *Ginkgocycadophytus nitidus* (Balme) de Jersey 1962 | + | | |
| *Microcachryidites antarcticus* Cookson 1947 | + | + | |
| *Podocarpidites* spp. | + | + | + |
| *Tsugaepollenites dampieri* (Balme) Dettmann 1963 | + | | |
| *T. trilobatus* (Balme) Dettmann 1963 | | | + |
| Spores | | | |
| *Baculatisporites comaumensis* (Cookson) Potonié 1956 | ++ | ++ | ++ |
| *Ceratosporites equalis* Cookson & Dettmann 1958 | + | + | |
| *Crybelosporites stylosus* Dettmann 1963 | | + | |
| *Cyathidites australis* Couper 1953 | + | | + |
| *C. minor* Couper 1953 | + | | |
| *Dictyophyllidites crenatus* Dettman 1963 | + | + | + |
| *Dictyotosporites speciosus* Cookson & Dettmann 1958 | + | | |
| *Foraminisporis dailyi* (Cookson & Dettmann) Dettmann 1963 | | + | + |
| *Fvoetriletes parviretus* (Balme) Dettmann 1963 | | | + |
| *Gleicheniidites* cf *G. circinidites* (Cookson) Dettmann 1963 | | | + |
| *Ischyosporites punctatus* Cookson & Dettmann 1958 | | | + |
| *Klukisporites scaberis* (Cookson & Dettmann) Dettmann 1963 | + | | + |
| *Krauselisporites linearis* (Cookson & Dettmann) Dettmann 1963 | | | + |
| *Kuylisporites lunaris* Cookson & Dettmann 1958 | | | + |
| *Lycopodiumsporites austroclavatidites* (Cookson) Potonié 1956 | | + | |
| *L. eminulus* Dettmann 1963 | + | + | + |
| *L. facetus* Dettmann 1963 | + | | |
| *L. nodosus* Dettmann 1963 | + | + | |
| *Murospora florida* (Balme) Pocock 1961 | | | + |
| *Neoraistrickia truncatus* (Cookson) Potonié 1956 | | + | |
| *Osmundacidites wellmanii* Couper 1953 | | | + |
| *Pilosisporites notensis* Cookson & Dettmann 1963 | + | | |
| *Spheripollenites psilatus* Couper 1958 | | | + |
| *Stereisporites antiquasporites* (Wilson & Webster) | + | | + |

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# Triassic Rocks of the Grants Head District and the Post-Permian Deformation of the Southeastern New England Fold Belt.

Evan C. Leitch and Malcolm A. Bocking

ABSTRACT. Folding and faulting of the Early Triassic Camden Haven Group show that significant deformation occurred in the eastern part of the New England Fold Belt subsequent to the Late Permian orogenic climax. Continuing activity from the Late Permian into the Triassic is indicated by near parallelism of basement faults, axes of rapid stratal thickening in the Early Triassic sequence, and faults and the axial traces of folds affecting these rocks. This relationship also suggests that deformation of the Camden Haven Group resulted mainly from movement on basement faults, although serpentinite diapirism may have been a contributory factor.

The Jolly Nose Conglomerate is a new formation in the Camden Haven Group, introduced for rocks lying between the Palaeozoic basement and the Laurieton Conglomerate in the Grants Head district.

## INTRODUCTION

A variety of structural, stratigraphic and radiometric studies have shown that terminal orogenesis affected the New England Fold Belt in the Late Permian about 255 m.y.b.p. (Crook, 1963; Binns, 1966; Leitch, 1969; Leitch and McDougall, 1979). However fault displacement of post-tectonic granite plutons (Shaw, 1969) and the fault-controlled emplacement of granite masses at least as young as 226 m.y. (Leitch, 1976) indicate that important tectonic movements continued for at least 30 m.y. after this orogenic climax. The Early Triassic Camden Haven Group of the Lorne Basin, mid-North Coast region, New South Wales (Fig. 1) provides a unique datum for assessing the nature and timing of movements late in the history of the southeastern part of the Fold Belt. Although Voisey (1939) noted faults cutting these rocks and recorded dip directions indicating a structure more complex than a simple basin-shaped depression, no previous systematic description of the structure of the Camden Haven Group has been published.

The present account details the nature and structure of the group in the Grants Head district (Fig. 1). The absence of major intrusive bodies which have elsewhere disturbed the Triassic strata, and the presence of inliers of Palaeozoic basement rock, make the district a favourable one for determining structural relations between the basement and its Early Triassic cover.

Localities not specifically shown on Fig. 1 are specified by 6-digit grid references read from 1:25,000 sheet Grants Head (1st edition, 9435-II-S) published by the New South Wales Department of Lands.

## STRATIGRAPHIC FRAMEWORK

### Basement Rocks

The basement rocks of the Grants Head district comprise Palaeozoic low-grade regional metamorphic rocks of the Port Macquarie Block, little deformed Late Palaeozoic strata of the Hastings Block, and serpentinite bodies emplaced close to the faulted contact between the blocks. These rocks are exposed both north of the Sapling Creek Fault where they outcrop extensively, and in a smaller inlier just north of Queens Lake (Fig. 1).

### Camden Haven Group

Voisey (1930) introduced the term Camden Haven Series for conglomerate, sandstone and shale of Early Triassic age (Helby, 1973; Holmes and Ash, 1979), preserved in a structural depression he termed the Lorne Basin, situated between Taree and Wauchope in the mid-North Coast region of New South Wales. Both Voisey, and Packham (1969) who changed the name to Camden Haven Group, recognised a general stratigraphic sequence in these rocks but it was not until the work of Pratt and Herbert (1973) that constituent formations were defined. The latter workers suggested a three-fold division: Camden Head Claystone comprising shale, sandstone and minor conglomerate, succeeded by and interfingering with the Laurieton Conglomerate, a prominently outcropping quartz conglomerate, in turn succeeded by the Grants Head Formation of interbedded sandstone and shale.

We have experienced some difficulty in applying this scheme in the Grants Head district. Although we have been able to map both the Grants Head Formation and the Laurieton Conglomerate as distinct lithostratigraphic units, the latter is underlain not by Camden Head Claystone, but by a distinctive recessive sequence of sandstone and conglomerate characterised by the presence of very abundant quartz sandstone clasts. In contrast to the Laurieton Conglomerate, this unit contains only modest amounts of detrital chert, jasper and vein quartz. For these rocks, formally defined in the Appendix, we propose the name Jolly Nose Conglomerate. The Camden Head Claystone forms a readily recognised unit within the Laurieton Conglomerate at Grants Head itself but we have not been able to map it further west. Rocks of similar character occur intercalated with Grants

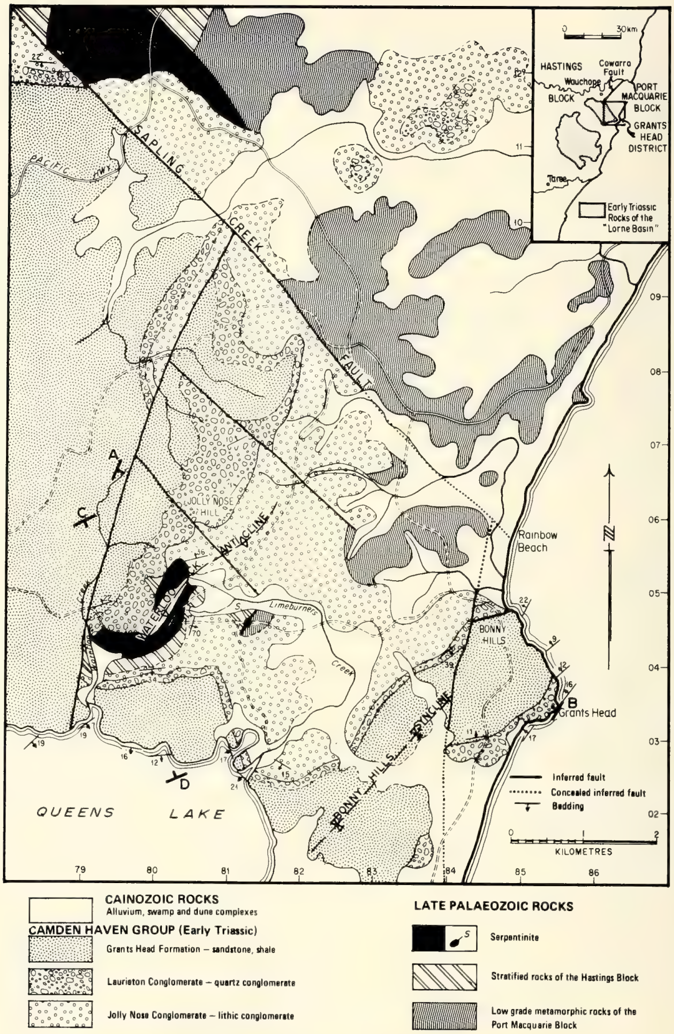


Fig. 1: Geological map of the Grants Head District. The symbols labelled A, B, C and D refer to the lines of section shown in Fig. 2.

Head Formation rocks (797033) and the stratigraphic significance of the claystone will need to be re-assessed after investigations in other parts of the Lorne Basin. At this time we consider the rocks at Grants Head to be best treated as a member within the Laurieton Conglomerate, that together with comparable rocks elsewhere in the Grants Head district constitute a distinctive sedimentary facies which may occur at several stratigraphic levels in the Camden Haven Group.

## STRUCTURAL GEOLOGY

### Structure of the Camden Haven Group

The Camden Haven Group has been both folded and faulted. East of Jolly Nose Hill two well defined folds, the Bonny Hills syncline and the Waterloo Creek anticline are separated by a broad anticline-syncline pair (Fig. 2). These structures all have axial traces trending about northeast, the broader folds plunge gently south-west but the Bonny Hills and Waterloo Creek folds, which are broken by faults, show minor plunge reversals along their traces and a culmination in the latter structure exposes an inlier of basement

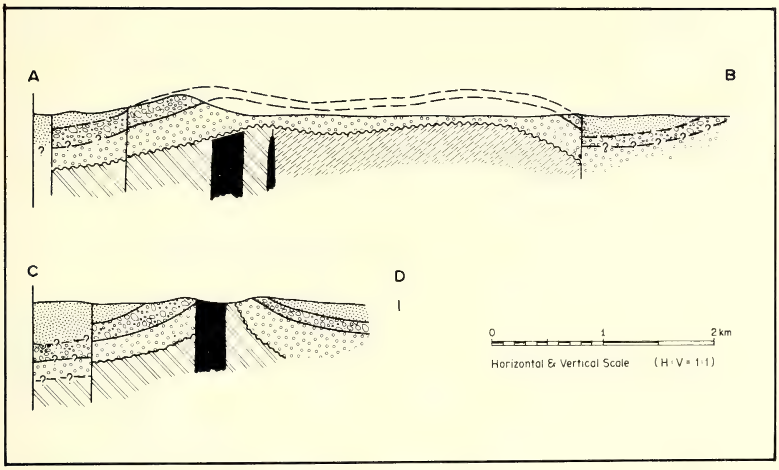


Fig. 2. Interpretative cross sections

rocks. West of the Waterloo Creek anticline the presence of a broad synclinal structure is indicated by the reappearance of the Laurieton Conglomerate west of Pacific Highway (around 86118, Fig. 1), but outcrop in the intervening area is too poor to allow the position of the axial trace of this structure to be determined. The disposition of the rocks suggests this fold plunges gently southwest.

Several prominent faults disrupt the Camden Haven Group. The northwest striking Sapling Creek fault is a vertical structure across which there has been uplift of the northeastern side of about 200 m subsequent to deposition of the Early Triassic rocks. Two smaller fractures of similar orientation are mapped from abrupt changes in the position of the base of the Laurieton Conglomerate along the ridge north of Jolly Nose Hill. Two northnortheast striking faults appear to be dominantly sinistral strike-slip features. One, which cuts obliquely across the Bonny Hills syncline, displaces the Laurieton Conglomerate on the eastern limb by perhaps as much as 1.3 km, although Quaternary alluvium prevents precise delineation of the amount of strike-separation. As the fold axial trace is also displaced horizontally by at least this amount, strike-slip movement is indicated. The second fault juxtaposes Grants Head Formation rocks against older strata outcropping in the core of the Waterloo Creek anticline just west of Waterloo Creek. Exposure here is not sufficient to determine whether the anticlinal trace has been displaced, but 4 km north the presence of an isolated ridge of Laurieton Conglomerate indicates horizontal strike displacement of about 2 km. If this is not a strike-slip fault then scissors movement must have taken place, downthrowing to the west in the south but upthrowing on this side in the north.

Laurieton Conglomerate is faulted against Grants Head Formation at the south end of Rainbow Beach. The fracture which terminates against the northnortheast fracture just to the west of Bonny Hills, has produced considerable disruption and near vertical dips in rocks exposed along the coast. It appears to be a vertical structure showing a minimum of 150 m upthrow to the north.

## SYN-DEPOSITIONAL FAULTING

Regional variations in the thickness of the Laurieton Conglomerate were discussed by Pratt and Herbert (1973), who suggested a general thickening of this unit westward, towards the source area they favoured. In the Grants Head district rapid variations in the thickness of the Conglomerate take place which appear to reflect more local controls on its accumulation. At Grants Head we estimate a minimum thickness for the Laurieton Conglomerate of 100 m, substantially more than the 45 m suggested by Pratt and Herbert, but as our value includes the thickness of the Camden Head Claystone and underlying conglomerate, the discrepancy is not as great as it first appears. On the western limb of the Bonny Hills syncline some 85 m of conglomerate is present immediately west of Bonny Hills, but further west, around Limeburners Creek, only about 45 m occurs, and on the southeastern limb of the Waterloo Creek anticline some 60 m. At Jolly Nose Hill on the northwestern limb of this structure 160 m of Laurieton Conglomerate is exposed, and west of the Pacific Highway 60 m. Although we cannot demonstrate that the upper and lower contacts of the Laurieton Conglomerate are time planes, the abrupt lower contact of the unit and significant provenance changes accompanying both the start and end of deposition, suggest the unit may be approximately isochronous. If this is the case, then the thickness variations probably reflect variations in the subsidence of the depositional realm, and indicate that these occurred on a local scale. The change across the Waterloo Creek anticline is particularly marked, and overall the pattern suggests differential fault-controlled subsidence was responsible for much of the observed variation.

## BASEMENT STRUCTURE AND BASEMENT-COVER RELATIONSHIPS

North of the Sapling Creek Fault the Palaeozoic basement is sliced by northnortheast trending faults along which strike-slip movement took place in Late Permian times (Leitch, *in press*). One of these fractures, the Cowarra Fault, separates the Hastings Block from the Port Macquarie Block and is truncated by a serpentinite mass associated with the Sapling Creek Fault in the northwest corner of Fig. 1. South of the latter fault the position of the boundary between these blocks is probably marked by the serpentinite masses exposed in the core of the Waterloo Creek anticline, implying sinistral transcurrent movement of 4 km on the Sapling Creek Fault prior to deposition of the Camden Haven Group.

The similarity in trend of basement faults north of the Sapling Creek fault, the axial trace of folds in the Camden Haven Group, the strike of several faults transecting these rocks, and the axes across which there are rapid changes in the thickness of the Laurieton Conglomerate, suggest that late movements on basement faults controlled both subsidence of the Early Triassic depositional realm and subsequent deformation of its fill.

Additional evidence for involvement of the basement during deformation of the Camden Haven Group comes from the Waterloo Creek anticline. Several observations indicate that the serpentinite mass forming the major part of the basement here, together with immediately associated Hastings Block rocks, moved upwards during formation of the anticline. Thus on the northwest side of the inlier serpentinite is in contact with Laurieton Conglomerate, and no Jolly Nose Conglomerate is exposed. The serpentinite close to this contact is frequently silicified, a feature also found in serpentinite cut by the Sapling Creek Fault. Immediately east of the serpentinite body Jolly Nose Conglomerate dips at angles up to 75° away from the Palaeozoic rocks, consistent with it having been shouldered aside by the rising core of the fold. Maximum dips on the western limb of the anticline occur south of Jolly Nose Hill adjacent to the Palaeozoic rocks. Our interpretation of the structure of this region is shown on the cross section C-D (Fig. 2). The absence of a recognizable fault along the crest of the fold north of the inlier suggests that the rise of basement rocks may have been confined very much to the area presently exposed. The fold possibly resulted from serpentinite diapirism driven by alteration of ultramafic rocks at depth not completely serpentinised during initial emplacement.

## CONCLUSIONS

The early Triassic Camden Haven Group in the Grants Head district has been both folded and faulted, with deformation controlled largely by fractures in underlying Palaeozoic basement rocks. Rapid thickness changes in at least one Early Triassic unit suggests that faulting also occurred during deposition of the Camden Haven Group, and the deformation of the rocks is a manifestation of the last stages of orogenesis that reached its peak in the Late Permian. The main deformation and metamorphism that mark the orogenic climax occurred in a relatively short time, perhaps less than 10 m.y. (Leitch, 1978), but at least in this part of the New England Fold Belt crustal instability lasting a much longer period is indicated both in the sedimentary record, as we have here shown, and in the record of granite emplacement that continued well into Triassic times (Leitch, 1976; Leitch and McDougall, 1979).

It is unclear whether these movements occurred throughout the New England Fold Belt or were restricted to its eastern part. There is accumulating evidence that post-tectonic granite bodies become younger from west to east and fault movements may also become younger in this direction.

In a temporal sense the Camden Haven Group constitutes molasse, material deposited after the climax of orogenesis and derived from the rising orogenic welt. However, rather than being preserved in a basin marginal to the orogen it has accumulated in a downfaulted region within the orogen itself. Development of a wrench regime in the later stages of Late Permian orogenesis is indicated by structural relationships in the region north of the Lorne Basin (Leitch, 1978). This regime apparently lasted well into the Triassic, and the 'Lorne Basin' possibly comprises a complex of lensoid grabens or pull apart structures that evolved during strike-slip faulting (Kingma, 1958; Crowell, 1974).

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## APPENDIX

### THE JOLLY NOSE CONGLOMERATE

The Jolly Nose Conglomerate is here defined for a lithostratigraphic unit of formational status exposed in the Grants Head district, northeastern New South Wales. It comprises a sequence of conglomerate and sandstone that unconformably overlies diverse Palaeozoic rocks as young as Late Permian (Leitch, *in press*) and is conformably overlain by the Early Triassic Laurieton Conglomerate (Pratt and Herbert, 1973). The unit contains no internal evidence of age but these relations suggest it is Early Triassic (Helby, 1973; Holmes and Ash, 1979) and it is considered to be the basal unit of the Camden Haven Group in the Grants Head district. The type section for the Jolly Nose Conglomerate consists of 100 m of strata exposed along a steep track on the south side of Jolly Nose Hill between 805053 and 804057. More accessible sections include those along the Pacific Highway between 798120 and 799188 and in a road aggregate quarry at 787120 where the contact with Laurieton Conglomerate is clearly exposed.

Massive and rudaceous rocks dominate the Jolly Nose Conglomerate. These are mainly well rounded cobble conglomerates with an open framework and a coarse quartzose sandstone matrix. The unit is characterised by the presence of mainly poorly-indurated quartz sandstone clasts, in contrast with the Laurieton Conglomerate in which most clasts are composed of chert, jasper and vein quartz. Frequently pebbly and sometimes cross-stratified quartz sandstones occur in the Jolly Nose Conglomerate.

# REPORT OF COUNCIL FOR THE YEAR ENDED 31st MARCH 1980

Presented at the 113th Annual General Meeting of the Society held on 2nd April 1980.

## INTRODUCTION

The Society has continued to fulfil its important function as a forum for generalist and interdisciplinary studies.

The only cloud in an otherwise auspicious outlook is the continuing serious financial position of the Science Centre, but it is confidently hoped that the establishment of the Science Centre Foundation will in due course reverse this situation. It is anticipated that a more generous and understanding attitude as to the role of the Society in the community on the part of the Commonwealth and State Governments will help in the process of re-establishing the Society and Science Centre on a sound financial footing.

## MEETINGS

Council held 11 meetings during the year and dealt with all the business matters of the Society. Attendance of members of Council at these meetings ranged from 9 to 16.

In its role of integrating diverse specialized scientific disciplines, the Society continued its policy of inviting speakers, expert in their field of endeavour, to deliver lectures at our monthly general meetings, at a level comprehensible to the well-informed layman and general scientist.

Nine general monthly meetings were held during the year in the Science Centre, together with two special meetings, namely the "Clarke Memorial Lecture" and "An Evening at the Macleay". Abstracts of these meetings will be published in the Journal and Proceedings; abstracts of the lectures given have already been published in the Society's Newsletter. The average attendance at the general monthly meetings, namely 35, and slightly less than last year, is considered by Council to be very disappointing. The lectures have been most interesting and stimulating and Council expresses its sincere thanks to all the speakers for the very high standard of their talks.

## ANNUAL DINNER

The Annual Dinner was held at the Sydney Hilton Hotel on 13th March 1980 and was attended by 98 members and guests. The guest speaker was the Hon. M. Justice M.D. Kirby, Chairman of the Law Reform Commission, the theme of his address being "Science and Law".

## AWARDS

The following awards for 1979 were made:

Edgeworth David Medal: Associate Professor G.C. Goodwin
Clarke Medal: Dr. L.A.S. Johnson
The Society's Medal: Dr. A.A. Day
The Archibald D. Olle Prize: Dr. R.J. Korsch
Clarke Memorial Lectureship: Dr. G.H. Taylor

## SUMMER SCHOOL

The Society held one Summer School from 14 - 18th January, 1980, for students who had just completed Year 11. The School was in the field of Astronomy with the theme title "Exploring the Universe". The lectures, which were held in the Science Centre, included talks on optical and radio astronomy, ranging from introductory material ranging to the frontiers of present research on neutron stars, black holes and quasars. The lecturers came from the University of Sydney, the University of N.S.W., Radiophysics Division of C.S.I.R.O., Anglo-Australian Observatory and Sydney Observatory. Visits were made to Fleurs Radio Observatory at Kemp's Creek, the site of Governor Brisbane's Observatory in Parramatta Park, the laboratories of the Radiophysics Division of C.S.I.R.O. and the Anglo-Australian Observatory, both at Epping, School of Physics at Macquarie University and Sydney Observatory. 47 students attended from 32 metropolitan secondary schools.

## MEMBERSHIP

The membership of the Society at 31st March 1980 was:

| | |
|---|---|
| Honorary Members | 13 |
| Life Members | 38 |
| Members | 331 |
| Associate Members | 50 |
| Company Member | 1 |

## PUBLICATIONS

Volume 112 of the Journal and Proceedings was published during the year.

Ten issues of the Society's Newsletter were distributed to members. Thanks are again extended to Dr. John Dulhunty for organizing the feature articles which have covered such a wide variety of interesting subjects.

## LIBRARY

During the year the Library has received and processed 2126 items from 378 institutions. There was a slight decrease in the number of requests on the Library for material; some 158 requests have been processed involving 2426 photocopies. The requests for photocopying received are as follows: Members 7; Universities and Colleges of Advanced Education 60; Commonwealth and State Government Departments 39; Private Firms 28; Museums 10; and Sundry Institutions, Hospitals etc. 14.

The Library services have continued to be maintained at a very high level by the Librarian, Mrs. Grace Proctor, although the Library is only open two full days each week.

ABSTRACT OF PROCEEDINGS 1979 - 1980

The Annual General Meeting and eight General Monthly Meetings were held in the Science Centre. In addition the Clarke Memorial Lecture and "An Evening at the Macleay" were held in the University of Sydney. Abstracts of the proceedings of all these meetings are given below.

APRIL 4th

112th Annual General Meeting. Location: the Auditorium, 1st Floor, Science Centre. The President, Professor F.C. Beavis, was in the Chair and 46 members and visitors were present.

The Annual Report of Council and the Annual Statement of Accounts were adopted. 2 new members were elected. 5 papers were read by title only.

The Clarke Medal was awarded to Professor D.T. Anderson F.R.S.; the Edgeworth David Medal to Dr. T.W. Cole and Dr. M.C. Clark; the James Cook Medal to Sir Lawrence J. Wackett Kt.; the Society's Medal to Mr. M.J. Puttock; the Archibald D. Olle Prize to Mr. D.S. King; and the Summer School Essay Prizes to Miss T. Pirola, Miss P. Gilson and Miss J. Muscolino.

Messrs. Wylie and Puttock, Chartered Accountants, were elected Auditors.

The Presidential Address "The Geology of Farm Water Storages" was given by Professor F.C. Beavis.

The incoming President, Professor D.H. Napper, was installed and introduced to members.

MAY 2nd

915th General Monthly Meeting. Location: Room A/B, 2nd Floor, Science Centre. The President, Professor D.H. Napper, was in the Chair and 34 members and guests were present. 3 new members were elected. 2 papers were read by title only.

An address "Fossil Fishing on Five Continents" was given by Dr. A. Ritchie, Curator of Fossils, The Australian Museum,

JUNE 6th

916th General Monthly Meeting. Location: Room A/B, 2nd Floor, Science Centre. The President, Professor D.H. Napper, was in the Chair and 26 members and guests were present. 5 new members were elected.

An address "Diagnostic Ultrasound" was given by Dr. G. Kossoff, Director, Ultrasonics Institute, National Acoustics Laboratory.

JULY 4th

917th General Monthly Meeting. Location: Room A/B, 2nd Floor, Science Centre. The President, Professor D.H. Napper, was in the Chair and 31 members and guests were present. 2 new members were elected.

An address "Mineral Supplies and the 'New Economic Order' - A Case for Trade Liberalization" was given by Professor G.J.S. Govett, Professor of Geology, School of Applied Geology, University of N.S.W.

JULY 12th

Clarke Memorial Lecture. Location: Stephen Roberts Theatre, University of Sydney. The Clarke Memorial Lecture for 1979 was given by Dr. G.H. Taylor of the C.S.I.R.O. Fuel Geoscience Unit, the title of the address being "The Response of Coal to Geological Stimulus".

AUGUST 1st

918th General Monthly Meeting. Location: Room A/B, 2nd Floor, Science Centre. The President, Professor D.H. Napper, was in the Chair and 37 members and visitors were present. 2 new members were elected.

An address "Concerning Irrationality" was given by Professor A.J. van der Poorten, Professor of Mathematics and Physics, Macquarie University.

SEPTEMBER 5th

919th General Monthly Meeting. Location: Room A/B, and Floor, Science Centre. The President, Professor D.H. Napper, was in the Chair and 25 members and visitors were present. 5 new members were elected.

An address "The Museum of Applied Arts and Science - its Past, Present and Future" was given by Mrs. M. Betteridge, Head of the Public Relations Department, Museum of Applied Arts and Science.

OCTOBER 3rd

920th General Monthly Meeting. Location: Room A/B, 2nd Floor, Science Centre. The President, Professor D.H. Napper, was in the Chair and 36 members and visitors were present. 5 new members were elected. 3 papers were read by title only.

An address "Conquering Cancer" was given by Professor M.H.N. Tattersall, Director, Ludwig Institute for Cancer Research, University of Sydney.

OCTOBER 17th

An Evening at the Macleay. Location: Macleay Museum, University of Sydney. Members and guests attended a private viewing of the exhibition "Sydney Unearthed - Archaeology and Anthropology of the Sydney Region".

NOVEMBER 7th

921st General Monthly Meeting. Location: the Auditorium, 1st Floor, Science Centre. The Vice-President, Dr. D.J. Swaine, was in the Chair and 40 members and visitors were present. 6 papers were read by title only.

A symposium was held with the theme "Our National Heritage and its Preservation". The panel of speakers comprised Mr. J.R. Morris, Director,

The National Trust of Australia (N.S.W.); Mr. G. Andrews, Director, Heritage and Conservation Branch, N.S.W. Planning and Environment Commission; and Mr. S.J. Smith-White, Head of Information Services, National Parks and Wildlife Service.

DECEMBER 5th

922nd General Monthly Meeting. Location: Room A/B, Science Centre. The President, Professor D.H. Napper, was in the Chair and 30 members and visitors were present. 2 new members were elected. One paper was read by title only.

An address "Numismatics as a Science" was given by Dr. A.W. McNicoll, Lecturer in Archaeology, the University of Sydney.

SCIENCE CENTRE

It is pleasing to report that there is a continuance of the progress of the Science Centre. The use of the conference and lecture room facilities has shown a very marked increase, so much so that there are now days when all facilities are fully booked for the whole day. This increased usage is to a large extent due to the very effective brochure on the Centre which was produced and distributed, and the cost of which was met by a private donation.

The Centre has been also developing its Conference organizing service and a number of conferences have already been organized successfully. It has contracted to organize further conferences during the coming year, the venues being in Sydney and elsewhere.

The financial situation of the Science Centre although improving as a result of the increased activities is still grave. A proposal which should lead to an alleviation of this situation is currently being considered and evaluated by Council and your four Directors on the Board of the Centre.

## CITATIONS

### EDGEWORTH DAVID MEDAL

Professor Graham Clifford Goodwin is awarded the Edgeworth David Medal for 1979 for his outstanding contributions to adaptive control. Adaptive control is the task of controlling a plant, parameters in which are unknown and, because of the need to identify the plant as well as to control it, is a much more difficult task than the control of a known plant. In particular, there is a major problem of preventing uncontrolled growth of internal signals before the plant has been adequately identified. Professor Goodwin has shown that satisfactory adaptive control is possible for a great many linear systems, via algorithms which are simple and intuitively appealing. His theory thereby provides justification for some fast adaptive controllers finding industrial applications which have been designed largely by intuition, and at the same time allows design engineers to categorize those industrial plants susceptible to adaptive control and then to design the controllers for these plants.

His work has involved the mastery of some highly technical issues in stochastic processes and non-linear systems, and the ability to match this material to the problems of industrial process control. It has enjoyed international acclaim.

### THE CLARKE MEDAL

The Clarke Medal for 1979 for distinguished work in the natural sciences is awarded to Dr. L.A.S. Johnson.

After graduating from the University of Sydney (B.Sc. Hons. 1948) Lawrie Johnson joined the staff of the National Herbarium of New South Wales, at the Royal Botanic Gardens, Sydney. His early research was on *Zamiaceae, Proteaceae, Casuarina* and *Eucalytus*, some of these groups remaining major continuing interests. He also spent much effort on improving botanical aspects of the Herbarium - helping to bring up-to-date collections which had been long neglected.

Still with the Royal Botanic Gardens, he was appointed in turn Special Botanist, Deputy Chief Botanist and, in 1972, Director. In 1962-63 he held the position of Australian Botanical Liaison Officer at the Royal Botanic Gardens, Kew. In 1971 the University of Sydney awarded him the degree D.Sc.

Twice Dr. Johnson has been President of the Linnean Society of New South Wales. He has also made very significant contributions to nature conservation in this State.

Dr. Johnson has contributed importantly to knowledge of many plant families and to several fields of botanical systematics. The theory of classification was the subject of a major paper in 1968. The higher-level systematics of several substantial plant families has been an increasing interest. His work on Proteaceae and Myrtaceae (with B.G. Briggs) has involved aspects of general classification systems of plants, the evolutionary history of the Southern Hemisphere flora, and the morphological interpretation of complex plant structures.

In collaboration with L.D. Pryor, he systemised the classification of Australia's most prominent plant assemblage - the eucalypts. Their outline of the major groups of eucalypts, with evaluation of relationships of individual species, is still subject to modification through continued study but has been widely adopted by other workers in this field.

Through his own contributions, stimulating collaboration with colleagues, and through advice widely sought and freely given, Dr. Johnson has added greatly to Australia's standing in the field of systematic botany and to knowledge of plants and their evolution.

### THE SOCIETY's MEDAL

The Royal Society of New South Wales Medal for 1979 is awarded to Dr. Alan Arthur Day, B.Sc, Ph.D. for his contributions to Education, Science, and for his services to the Society.

Dr. Day's special field of interest is geology and geophysics, especially the structure of continents and ocean basins. He has carried out research on these topics in the United Kingdom and North America, as well as extensively in Australia and the Southwest Pacific. He has participated in numerous oceanographic expeditions, including several trips underwater in submarines.

His early geophysical work on the English Channel, conducted while at Cambridge, has recently come into prominence in the oil exploration of that region.

His more recent interests have been within the fields of solid earth Geophysics, Physical Oceanography, and include geological interpretation of geophysical field data in Eastern Australia; Petrophysical properties of rocks in relation to geophysical interpretation, and also on the continental margins of eastern Australia.

Currently he is studying water movements and structure of estuarine waters, particularly that of the Parramatta River, and is making important contributions to environmental reclamation and rehabilitation of this industrially polluted river.

Alan Day joined the staff of the Department of Geology and Geophysics at Sydney University in 1957 and has made a significant contribution in both initiating and establishing undergraduate courses in Fundamental Geophysics and Global Tectonics, and more recently Physical Oceanography, he has also co-ordinated interdisciplinary courses in Marine Science.

In addition to his administrative and teaching work for his department, Alan Day has served the University on the Faculty of Science (for which he has been Sub-Dean) and as a member of the University Academic Board; he is also a member of the Australian National Committee for Geophysics under the auspices of the Australian Academy of Science.

Throughout his career Alan Day has assumed a devoted, conscientious and highly successful role in University teaching of Geology, and in bringing to the community a general knowledge and understanding of geological science, this being through his field and lecture courses conducted in Adult Education which have been greatly appreciated by the WEA students who have come from many varied walks of life.

Alan Day's devotion to matters concerning the Royal Society of N.S.W. is regarded by his scientific colleagues as a major contribution to science in general, and has extended over the entire period since he joined the Society in 1952, during this time he has been involved in all aspects of the Society and has served on our various committees, during this time he has been a Council member for twenty years, being President in 1965. He was Journal Editor for six years, and during this period persuaded Council to agree to changing the Journal format to that of a two column presentation, and also to printing the contents on the cover.

Alan has involved his whole family in the affairs of the Society - for in 1962 he persuaded his father, the late Arthur Day, to become voluntary Librarian, and more recently, Alan's wife, Judy, has been the Society's Assistant Secretary, responsible for the day to day running of the Society's affairs.

Alan was responsible for organising, and physically moving the Society's very extensive library from the old Science House in Gloucester Street to the Science Centre in Clarence Street; in this he involved as very willing helpers his children.

Perhaps his most significant role in the Society's affairs is his current one of Hon. Treasurer for in these most difficult financial times Alan has been responsible for guiding the Society through his sound husbanding and management of the funds available.

Alan Day is indeed a very worthy recipient of the Society's Medal.

# OBITUARIES

## ARTHUR DE RAMON PENFOLD

Arthur Penfold, a former Director of the Museum of Applied Arts and Sciences in Sydney and for many years a very active member of the Society, died at Canberra on 16 June, 1980, in his 90th year. He was elected a member of the Society in 1920, and in the sixty years of his membership he served as President (1935), Vice-President (1936-38), Honorary Treasurer (1938-39 and 1941-42), Honorary Secretary (1940-41), and as a member of Council (1929-35). He was a prolific contributor of papers to the Journal, and in 1951 he was awarded the Society's Medal for services to science and to the Society.

He was born in Sydney on 4 August, 1890, the son of David and Elizabeth Penfold (formerly Elizabeth Emanuel). His father died at the early age of 37, leaving his young widow and four sons in straitened circumstances. Arthur, as the eldest son, was obliged to leave school at 14 to earn money for the support of his family.

His first employment, in 1904, was as an office-boy with the English paint firm of Wilkinson, Heywood and Clark Ltd., at 168 Clarence Street, Sydney, at the remuneration of five shillings a week. After two years he joined M.H. Lauchlan & Co., one of a number of "colonial representatives" for United Kingdom manufacturers and exporters, in this case for linseed oil, paints and other materials used in the surface coating industry. He rapidly rose to the position of Book-keeper, and then, in 1908, he became Accountant for the Company. This contact with the paint and varnish industry, although at first on the commercial side, stimulated in him the desire to understand its chemical and technological basis, and he resolved to study chemistry at evening classes at the Sydney Technical College, the fees for which were paid for the first year (1908) by the Manager of M.H. Lauchlan & Co. As a reward for topping the annual examinations, he was thereafter exempt from fees, and was a consistent prize-winner throughout his studies at the College.

The turning-point in his chemical interests may be held to date from 1914, when attendance at a lecture that year on the chemistry of the oil-yielding flora of Australia, delivered by H.G. Smith, then Economic Chemist at the Sydney Technological Museum (now the Museum of Applied Arts and Sciences), aroused his enthusiasm for terpene chemistry. It is therefore not surprising to find him taking the first opportunity (in the year 1915) of entering the essential oil field, when he secured appointment as Research Chemist and Assistant Works Manager to the eucalyptus oil distillers and merchants, Gillard Gordon Ltd. The experience gained here no doubt led to his being selected for engagement in the special laboratory, set up by a group of businessmen and Penfold's chemistry teachers at the outbreak of the First World War for the purpose of applying Smith's discoveries to industry. Smith's chemical career at the Museum was now drawing to a close, and in anticipation of his retirement, the Public Service Board of New South Wales decided to appoint an assistant to ensure continuity of the work (a recent decision by the Board has resulted in the termination of phytochemical researches at the Museum). Penfold was the successful candidate for the post, and on 1 September, 1919, he entered on duty as Assistant Chemist at the Museum; Smith retired the following year.

Penfold's long and distinguished career in the chemistry of terpenes and of the volatile oils of the Australian flora was now launched, aided by his assistant, F.R. Morrison (1895-1967), who had joined the Museum in 1916. Space does not permit more than a brief summary of meritorious work in this field, for which he was to receive a number of awards. These included the H.G. Smith Memorial Medal of the Royal Australian Chemical Institute (1934), and in 1954 the American Chemical Society nominated him for its Fritzsche Award, an international distinction comprising a gold medal and a gift of $1000. He delivered the Fritzsche Address at the American Chemical Society meeting at Kansas City, Missouri, on 26 March, 1954.

The phytochemical work for which he was thus recognized was largely in the field of volatile plant oils ("essential oils") of the Australian flora. He isolated and characterised many new compounds such as croweacin, baeckeol, calythrone, leptospermone, zierone, angustione, dehydroangustione, and the eremophilones. These attracted overseas attention, particularly with the English terpene chemist, Sir John Simonsen, Professor of Chemistry at the University College of North Wales, and first recipient of the Fritzsche Award, with whom Penfold collaborated on the elucidation of the structures of these substances. As early as 1921 Penfold had established the position of the double bond in Smith's piperitone, and in collaboration with Smith, he demonstrated how menthol and thymol might be synthesised from it. The names of Penfold and Morrison will, however, be always associated with very extensive investigations into the phenomenon of chemical variation within a plant species with respect to its volatile oil, and referred to by them as "physiological forms".

Penfold's researches are recorded largely in the Society's *Journal and Proceedings*, to which he contributed no fewer than 82 papers. In collaboration with his botanical colleague, J.L. Willis, who later in 1960 succeeded Morrison as Director of the Museum, he wrote the well-known text-book "The eucalypts: botany, chemistry, cultivation and utilization" (London: Leonard Hill, 1961). He also, together with Morrison, made a substantial contribution to Ernest Guenther's six-volume work "The essential oils" (New York: D. van Nostrand, 1948-52). He was also the Liversidge Lecturer at the Hobart meeting of 1949 of the Australian and New Zealand Association for the Advancement of Science.

Penfold gave freely of his time and talents in an honorary capacity to a number of organizations. In addition to his services to this Society, already enumerated, he was one of the founders of the Sydney Technical College Chemical Society, later to become the University of New South Wales Chemical Society when that University had taken over the Diploma Courses of the College. He was

Honorary Secretary to that Society from the day of its first meeting (2 August, 1913) until 1948. He was an early member of the Royal Australian Chemical Institute having been admitted in 1918 (it was founded in the previous year); he was elevated to the Fellowship in 1924. In later years he served on the N.S.W.State Advisory Committee of the C.S.I.R.O.

The pharmaceutical implications of his work, such as the medicinal applications of Australian essential oils, and his synthesis of menthol and thymol, led to his being made an Honorary Member of the Pharmaceutical Society of N.S.W., and in 1935 he was invited by the Pharmaceutical Society of Victoria to be its Centenary Guest at the Society's Centenary Conference at Melbourne.

In 1927 he was appointed by the Public Service Board of N.S.W. to assume control of the Museum of Applied Arts and Sciences, a position he was to hold until his retirement as Director in December 1955. With his enormous capacity for work, he added to his already remarkable scientific output a whole-hearted devotion to the welfare of the Museum, as well as to the museum scene generally in Australia. He was among the delegates who attended the now historical Australian and New Zealand Museums and Art Galleries Conference held at Melbourne in 1936 through the Carnegie Corporation of New York, and which led to the founding of the Museums Association of Australia in the year following. In that year, at its first meeting, Penfold was elected Secretary-Treasurer of the Association, a position he held continuously until 1955: for his servies to the M.A.A. he was later made an Honorary Fellow. In 1939 he was awarded a grant by the Carnegie Corporation to make a study tour of museums in Europe and in the U.S.A., particularly with respect to the planning, construction and management of science museums. This was part of the preliminary planning necessitated by the announcement by the N.S.W. Government of its intention to provide new accommodation for the inadequately housed Museum, but a month prior to his return, the Second World War had broken out, and all plans for a new building were abandoned for another 40 years.

The War brought with it changes of activity for many, and Penfold's talents were also enlisted. In 1942, he was seconded by the State to act as Deputy Director for New South Wales of the Federal Government's Scientific Liaison Bureau, set up to ensure that all problems of a scientific nature arising from the conduct of the war should be directed into the proper channels for investigation, and that scientists best qualified be approached to deal with them. In 1943 he was appointed a member of the Plastics Advisory Committee, set up by the Premier of the day of N.S.W., the Hon. W.J. McKell, M.L.A. (later Sir William McKell). This was followed in 1945 by a visit, in company with Mr. C.H. Hunt, Teacher of Industrial Chemistry at Newcastle Technical College, to the U.S.A., Canada and Europe to investigate recent developments in the plastics industry on behalf of the N.S.W. Government, and to advise on training technical personnel in this field. For services to the plastics industry he was made a Life Member of the Plastics Institute of Australia, of which he was also the first Technical Secretary, 1961 - 64.

It was earlier mentioned that the first eleven years of Penfold's working life were spent in the paint and varnish industry, and his interest in this subject never left him (his first scientific paper, in fact, was entitled "The analysis of commercial red lead", read to the Sydney Technical College Chemical Society at its first meeting in 1913). He served the Standards Association of Australia since its foundation in 1927 as a member and chairman of technical committees dealing with standards for materials used in the surface coating industries. He also served the S.A.A. as first chairman of its National Committee for Essential Oils (1965). In 1946 he was elected Foundation Chairman of the Australian Section of the Oil and Colour Chemists' Association, and in 1956 was elected an Honorary Member of the parent body in the United Kingdom. He was also Chairman of the N.S.W. Branch of the Australian Section in 1947 - 48.

Some personal recollections might appropriately close this account. Those who knew him, and especially those who worked with him, will remember his nimble mind, retentive memory and prodigious capacity for work. Always impatient for quick results, he placed diligence, efficiency and punctuality in the highest rank of human virtues, and shortcomings in these qualities in others provoked him to outbursts which left the recipient in no doubt as to his dissatisfaction. These storms quickly subsided, and he could be as often genial, generous and helpful to those about him. He will long be remembered for his competence as a chairman, skilled in the rules and with a memory for constitutions, who cut short loquacity and drove meetings to accomplish the maximum in the minimum of time. His early accountancy and book-keeping training made him a valued treasurer.

In 1915 he married Eunice Gardner (died 1957), the daughter of Francis E. Gardner; in 1959 he married her sister, Lorna. He is survived by Dulcie, his daughter from the first marriage.

H.H.G. McKern.

## ADOLPHUS PETER ELKIN

Emeritus Professor A.P. Elkin was born at Maitland, N.S.W. on 27th March, 1891, attended its high school, and then spent four years as a bank officer in nearby country branches. He graduated at the University of Sydney in 1915, became an Anglican priest in 1916 at Newcastle and then served in isolated places in neighbouring districts until he became Vice-warden (1919-21) at St. John's College, Armidale. While rector at Wollombi (1922-25) he gave tutorial lectures on prehistory and social anthropology in Newcastle for the University of Sydney, to which he submitted his M.A. thesis on Australian Aboriginal religion (1923); his subject for his Ph.D. at the University College, London, was their myth and ritual (1927). He began his fieldwork in 1927-28 on the social organisation, religion and mythology of a number of Kimberley tribes. The next few years were very busy indeed for him - he became rector of Morpeth College (1929-37) and while there he did his second major fieldwork in northeast South Australia in 1930, and was appointed lecturer-in-charge and later Professor of Anthropology, University of Sydney, in 1934. During this period he wrote *Morpeth and I* (1937), and three Morpeth booklets on *Understanding the Australian Aborigines* (2, 1931), *Christian Science* (5, 1932) and *Christian Ritual* (8, 1932), and in later years *The Centenary of the Parish of Muswellbrook* (1943), *The Wollombi and the Parish of Wollombi* (1946), and the massive *The Diocese of Newcastle* (1955).

His two field projects were concerned not only with gathering data but with ascertaining the part played by kinship, social organisation, religion and magic in the cohesion and functioning of Aboriginal society, and with the link between the living people and their dreamtime. From the 1930's onwards he visited tribal groups all over Australia for various purposes. The results of these studies are epitomised in *The Australian Aborigines: How to Understand Them* (1938, 5th ed. 1979): *Aboriginal Men of High Degree* (1946): *Oceania Monograph* 2 (1933) on totemism, 3 (1937) on linguistics, and 19 (1972) on Arnhem Land rituals; *Oceania Linguistic Monograph* 16 (1974) on the Ngarinjin language with H.H.J. Coate; several children books (1961, 1966), and many papers in *Oceania* and other journals.

His hobby was music - he had been a church organist in his early years - and he wrote a study of Arnhem Land music with Professor T.R. Jones (*Oceania Monograph* 9, 1958), and *Songs of the Songmen* with W.E. Harney (1949. He also recorded a vast number of L/P discs in association with the Australian Broadcasting Commission. The integral link between religion and art led him into studying the Wandjina cave paintings in the Kimberleys, and rock engravings in the Wollombi area. He was co-author of *Art in Arnhem Land* with R.M. and C.H. Berndt (1950).

Elkin studied and wrote profusely on the problems of the Aborigines and their place in Australian society. He was at various times a representative on various missionary councils, chairman of the Aboriginal Welfare Board of N.S.W. (1941 - 68), President of the Association of Native Races (1932-62), and attended many governmental and other conferences, often as chairman, from which substantial and far-reaching changes emanated in regard to Aboriginal welfare in Australia. In this field he wrote *A Policy for the Aborigines* (1933); *Citizenship for the Aborigines - a National Policy* (1944); *Post-War and the Aborigines* (1945); *The Franchise* (1946); *Aborigines and Citizenship* (1959), and many articles in newspapers and magazines. He applied his anthropological knowledge to White society in *Our Opinions and the National Effort* (1941); *Society, the Individual and Change* (1941); *Marriage and the Family in Australia* (Ed., 1957); *Man, Society and Change* (1946), and *Changes that are upon us* (1943).

On the centenary of the death of an old friend, Elkin and the late Emeritus Professor N.W.G. Macintosh organized an international symposium at the University of Sydney and edited the ensuing volume of papers - *Grafton Elliot Smith: The Man and his Work* (1974). Elkin then edited *Collected Papers: In Memoriam - N.W.G. Macintosh* (1979) as *Oceania Monograph 22*. Elkin's research also extended to the Pacific peoples. He visited New Guinea to study the post-war situation in 1946 for the Administration and again in 1949 for the South Pacific Commission, producing *Social Anthropology in Melanesia: A Review of Research* (1953). In 1956 he led the Nuffield/Sydney University project in the Highlands region. He also wrote *Wanted - A Charter for the Peoples of the Southwest Pacific* (1943).

Elkin was also very active in the organisation of science as chairman of the Committee on Anthropology (1933-48), member of the executive Committee (1942-45), and chairman of the N.S.W. division (1954-55) of the A.N.R.C.; President of section F (1935), honorary secretary of the Jubilee Congress, Sydney (1962) of A.N.Z.A.A.Z., for which he edited the volume, *A Goodly Heritage: Science in N.S.W.;* Australian member of the Permanent Council and vice-president of the 10th Congress (Hawaii 1966), for which he wrote the *Pacific Science Association: Its History and Role in International Co-operation* (1961); Trustee of the Australian Museum (1946-72) and President of the Board (1962-68); Fellow of the Australian Science Research Council (1953-79); Honorary Secretary (1938-40, 1942) and President ( 1940 ) of the Royal Society of N.S.W.; President of the Anthropological Society of N.S.W. (1934, 1940-44, 1956-59). At the University of Sydney he was Professor of Anthropology for 22 years (1934-56), Fellow of the Senate (1956-59), editor of *Oceania* since 1933, founder of Archaeology and Physical Anthropology

in *Oceania*, and author of *Oceania: A History, 1930-70 (Oceania Monograph*, 16, 1970).

Many other of his activities have been left out of this brief outline of his life. His writings comprise some 14 books, 6 monographs, 11 booklets and numerous papers, and the editing of 5 books - a truly remarkable record of his unbounded energy and tireless devotion to his work. Prior to his death he was preparing several major studies for publication and arrangements have been made for their completion.

Honours were duly accorded to this great scientist, the results of whose research and its application to the solution of social problems have been so productive. He delivered the Livingstone Lectures at Camden College (Sydney, 1940), John Murtagh Macrossan Memorial lecture, University of Queensland (1944), and the David lecture, A.N.R.C., (Hobart 1949). He was awarded the Medal (1949) and the James Cook medal (1955) by the Royal Society of N.S.W., Mueller medal by A.N.Z.A.A.S. (1957), the Herbert E. Gregory (1961) by the Pacific Science Association, the C.M.G. in 1966 and an honorary D. Litt. in 1970. In his 73rd year he was honoured with a volume of essays, *Aboriginal Man in Australia* (1965) edited by R.M. and C.H. Berndt.

Elkin was a quiet and friendly man, a scientist, historian and humanitarian, whose great knowledge of the Aborigines and their problems, and his equally great inspiration to his wide circle of colleagues, will be sadly missed. As Professor Berndt said "His impact has been....felt over a very wide field indeed. In fact for many years Anthropology in Australia *was* Professor Elkin; and he was the source of all personal stimulation in that discipline in this country." He died in his chair at a meeting of the Council of International House on 9 July, 1979, at the age of 88. His work has been described by R.M. Berndt in *Mankind*, V, 1956 and the above festschrift (1965), by himself in the *Int. Soc. Sci. J.*, XXV, 1973, *Oceania*, VIII (1938), X (1939) and XXVI (1956).

F.D. McCarthy

## DAVID PAVER MELLOR

One of the Australian pioneers of co-ordination chemistry, Emeritus Professor D.P. Mellor, died of a stroke on 9 January, 1980. David Paver Mellor was born in Launceston in 1903 and educated at Launceston High School. His first job after graduating from the University of Tasmania was a chemist with the Electrolytic Zinc Co., Risdon. In 1929, however, he joined the staff of the University where he spent the next twenty six years, being promoted to Reader in Organic Chemistry in 1948.

It was at the University of Sydney that Professor Mellor performed his most important studies into the properties and structures of metal complex compounds. Much of this pioneering work was published (25 papers in all) in the Journal and Proceedings. This did much to re-establish the reputation of the Journal in chemical circles.

It was also during this period at the University of Sydney that he played an intensely active role in the affairs of the Society. He joined the Society almost immediately on moving to Sydney and was elected to Council in 1936. As a result of spending a period of sabbatical leave with Professor Linus Pauling at the California Institute of Technology, he was unable to serve on Council again until 1939. He became President in 1941, his Presidential Address being entitled 'The Stereochemistry of Square Complexes', an area where he had already established for himself an international reputation. He was Vice-President of the Society until mid-1942 when he resigned to take up the position of Honorary Editorial Secretary. He was to hold this position until the end of the War. Then followed two years (1946-47) as Honorary Secretary, after which he was re-elected Vice-President for a further one year term. He was awarded the Society's Medal in 1954.

In 1955 he was appointed Professor of Inorganic Chemistry at the University of N.S.W. The following year he became Head, School of Chemistry, a position he held until 1968 when he became Dean of the Faculty of Science. He vacated this position in December 1969 on retirement from the University, when the title of Emeritus Professor was bestowed upon him.

D.P. Mellor was the author of numerous scientific articles as well as several books dealing with the history of chemistry ("The Evolution of the Atomic Theory", Elsevier, 1971, and "The Role of Science and Industry in the Second World War", Official War History) and co-ordination chemistry ("Chelating Agents and Metal Chelates", co-editor with F.P. Dwyer, Academic Press, 1964). He made significant contributions to chemical education, being *inter alia* Chief Examiner for the N.S.W. Leaving Certificate and Chief Examiner for Science (Higher School Certificate). He also served as a member of the Secondary Schools Board. In recognition of his outstanding contributions to chemical education, the University of N.S.W. in 1972 endorsed the Mellor Lecture and Medal for Chemical Education. One of the lecture theatres in the School of Chemistry is also named after him.

Professor Mellor was awarded the Doctor of Science degree by the University of Tasmania for his work on the structures of platinum and palladium

complexes and he delivered the First Kurth Memorial Lecture at that university in 1977. The Royal Australian Chemical Institute recognized his distinguished contributions to chemistry by bestowing upon him the following honours: the H.G. Smith Medal (1949); the Liversidge Medal (1951); and the Leighton Medal (1975). He was also awarded the Dwyer Memorial Medal (1969).

David Mellor was a quiet yet very approachable and kindly man. He will long be remembered with affection by his former students and colleagues. His lectures, reknown for their clarity and perceptive insights, were presented with both style and enthusiasm. He leaves a widow and two daughters.

D. H. Napper

## JOYCE WINIFRED VICKERY

Joyce Winifred Vickery was born at Homebush and educated at the Methodist Ladies College, Burwood. Her early life was influenced by her father who was a member of the Royal Society and who travelled in the rural areas to oversee property interests. He was a natural historian with particular interests in the grasses of pastures. Joyce often accompanied him and developed similar interests. She graduated in 1931 as Batchelor of Science with Honours in Botany, from the University of Sydney. She carried out post graduate work in the Botany Department on the vegetative reproduction of the insectiverous plant *Drosera* and on aspects of seed germination in grasses and was awarded the degree of Master of Science in 1933. From 1931-1936, she worked jointly with Lilian Fraser on the community ecology of the Upper Williams River and Barrington Tops, and three papers were published. This is regarded as important pioneer work on subtropical rainforest. Her work at this time on the comparative anatomy of grasses lead her to her major specialisation in the taxomony of Australian grasses. She has collected extensively in N.S.W. and elsewhere in Australia, specialising particularly in the Kosciusko region. In 1935, she became a member of the Royal Society of New South Wales.

In 1936, Joyce Vickery joined the staff of the National Herbarium of New South Wales. She was instrumental in the development of scientific standards at the herbarium and was very generous of her time in assisting less experienced colleagues. She was largely responsible for initiating the Contributions from the New South Wales National Herbarium and the Flora of New South Wales Series. Her research into the taxonomy of the Australian grasses has involved periods of work at the Royal Botanic Gardens, Kew, the United States National Herbarium, Washington, and other institutes abroad. She became an authority on native grasses and has published Australia-wide revisions of *Festuca, Deyeuxia, Agrostis, Amphipogan* and *Danthnia*, as well as the new genus *Dryopoa* J. Vickery. In all, she has published almost forty papers. She was awarded the degree of Doctor of Philosophy, from the University of Sydney in 1959, and the Clarke Medal for 1964 from the Royal Society of New South Wales.

In 1960, Dr. Vickery helped the police solve the Graeme Thorne kidnapping. She identified fragments of several plant species found on the body. One of them was a grass, and her special knowledge of the soil requirements of that particular grass narrowed down the likely area of the crime. An intensive search located a garden where all the species identified on the body were growing. When the police confronted the suspected murderer with this and other evidence that they had, he confessed to the crime. In 1962, she was made an MBE, largely as a result of this botanical detective work.

Dr. Vickery was appointed as Senior Botanist at the National Herbarium of New South Wales in 1964 and retired in 1967. She continued her research work after retirement and was appointed as Honorary Research Fellow for the period 1973-79. For many years, she has played an important role in nature conservation, particularly in the Kosciusko area. She became very active in the affairs of the Linnean Society of New South Wales, joined the Council in 1969 and served as Honorary Treasurer from 1971-1978. Initially, it was to be for a three month period to help the Linnean Society out of its difficulties, but she continued as Treasurer and her wisdom and expertise undoubtedly saved it from financial ruin. The Linnean Society has renamed its Scientific Research Fund "Joyce W. Vickery Scientific Research Fund" as a memorial to her generosity and contribution to the Society. The first grant from this research fund was made in February 1980.

In 1970, when the Sydney Cove Redevelopment Authority served notice of resumption of the site of Science House in Gloucester Street, the property owned jointly by the Royal Society, the Linnean Society and the Institute of Engineers, Dr. Vickery became involved in the Science Centre Project which searched for an alternative site to re-invest the monies received as compensation for the old property. After innumerable negotiations, the present site of Science Centre at 35 Clarence Street was found in 1973. She believed absolutely in the wisdom of it all, in spite of a staggering mortgage of $1.25 million to re-develop the new property and no prospects of a sufficient positive

cash flow in the near future (of 1973). She remained on the Board of Directors of Science House Pty. Ltd. until her death.

Dr. Vickery died at her home in Cheltenham on May 29th, at the age of 70.

H. Martin

## AWARDS OF THE CLARKE MEDAL

Established in memory of
The Revd. WILLIAM BRANWHITE CLARKE, M.A., F.R.S., F.G.S.

Vice-President from 1866 to 1878

The Clarke Medal is considered annually for distinguished work in the natural sciences done in, or on, the Australian Commonwealth and its territories.

| | |
|---|---|
| 1878 | Professor Sir Richard Owen |
| 1879 | George Benthm |
| 1880 | Professor Thomas Huxley |
| 1881 | Professor F. M'Coy |
| 1882 | Professor James Wright Dana |
| 1883 | Baron Ferdinand von Mueller |
| 1884 | Alfred R.C. Selwyn |
| 1885 | Sir Joseph Dalton Hooker |
| 1886 | Professor L.G. De Koninck |
| 1887 | Sir James Hector |
| 1888 | Rev. Julian E. Tenison-Woods |
| 1889 | Robert Lewis John Ellery |
| 1890 | George Bennett |
| 1891 | Captain Frederick Wollaston Hutton |
| 1892 | Sir William Turner Thiselton Dyer |
| 1893 | Professor Ralph Tate |
| 1895 | Robert Logan Jack |
| 1895 | Robert Etheridge, Jnr. |
| 1896 | The Hon. Augustus Charles Gregory |
| 1900 | Sir John Murray |
| 1901 | Edward John Eyre |
| 1902 | F. Manson Bailey |
| 1903 | Alfred William Howitt |
| 1907 | Professor Walter Howchin |
| 1909 | Dr. Walter E. Roth |
| 1912 | W.H. Twelvetrees |
| 1914 | Sir A. Smith Woodward |
| 1915 | Professor W.A. Haswell |
| 1917 | Professor Sir Edgeworth David |
| 1918 | Leonard Rodway |
| 1920 | Joseph Edmund Carne |
| 1921 | Joseph James Fletcher |
| 1922 | Richard Thomas Baker |
| 1923 | Sir W. Baldwin Spencer |
| 1924 | Joseph Henry Maiden |
| 1925 | Charles Hedley |
| 1927 | Andrew Gibb Maitland |
| 1928 | Ernest C. Andrews |
| 1929 | Professor Ernest Willington Skeats |
| 1930 | L. Keith Ward |
| 1931 | Robin John Tillyard |
| 1932 | Frederick Chapman |
| 1933 | Walter George Woolnough |
| 1934 | Edward Sydney Simpson |
| 1935 | George William Card |
| 1936 | Sir Douglas Mawson |
| 1937 | J.T. Jutson |
| 1938 | Professor H.C. Richards |
| 1939 | C.A. Sussmilch |
| 1941 | Professor Frederic Wood Jones |
| 1942 | William Rowan Browne |
| 1943 | Walter Lawry Waterhouse |
| 1944 | Professor Wilfred Eade Agar |
| 1945 | Professor William Noel Benson |
| 1946 | J.M. Black |
| 1947 | H.L. Clark |
| 1948 | A.B. Walkom |
| 1949 | Rev. H.M. Rupp |
| 1950 | I.M. Mackerras |
| 1951 | F.L. Stillwell |
| 1952 | J.G. Wood |
| 1953 | A.J. Nicholson |
| 1954 | E. de C. Clarke |
| 1955 | R.N. Robertson |
| 1956 | O.W. Tiegs |
| 1957 | Irene Crespin |
| 1958 | T.G.B. Osborn |
| 1959 | T. Iredale |
| 1960 | A.B. Edwards |
| 1961 | C.A. Gardner |
| 1962 | H. Waring |
| 1963 | G.A. Joplin |
| 1964 | J.W. Vickery |
| 1965 | M.J. Mackerras |
| 1966 | D. Hill |
| 1967 | S. Smith White |
| 1968 | H.G. Andrewartha |
| 1969 | S.W. Carey |
| 1970 | G. Whitley |
| 1971 | N.T. Burbridge |
| 1972 | H. King |
| 1973 | M.D. Hatch |
| 1974 | C.H. Tyndale-Biscoe |
| 1975 | J.N. Jennings |
| 1976 | Lilian R. Fraser |
| 1977 | A. Trendall |
| 1978 | D.T. Anderson |
| 1979 | L.A.S. Johnson |

## CLARKE MEMORIAL LECTURESHIP

The lectureship is awarded for the purpose of the advancement of Geology. The practice of publishing the lectures in the Journal began in 1936.

| | |
|---|---|
| 1903 | T.W.E. David |
| 1906 | E.W. Skeats (2 lectures) |
| 1907 | T.W.E. David (2 lectures) |
| 1907 | W.G. Woolnough |
| 1907 | E.F. Pittman |
| 1907 | W.S. Dun |
| 1918 | R.J.A. Berry |
| 1919 | T.W.E. David |
| 1936 | W.G. Woolnough |
| 1937 | H.C. Richards |
| 1938 | C.T. Madigan |
| 1939 | Sir John S. Flett |
| 1940 | E.J. Kenny |
| 1941 | C.A. Sussmilch |
| 1942 | E.C. Andrews |
| 1943 | H.G. Raggatt |
| 1944 | W.H. Bryan |
| 1945 | E.C. Hills |
| 1946 | L.A. Cotton |
| 1947 | H.S. Summers |
| 1948 | Sir Douglas Mawson |
| 1949 | W.R. Browne |

CLARKE MEMORIAL LECTURESHIP (Cont.)

| | | | |
|---|---|---|---|
| 1950 | F.W. Whitehouse | 1967 | S.W. Carey |
| 1951 | A.B. Edwards | 1969 | A.E. Ringwood |
| 1953 | M.F. Glaessner | 1971 | D.H. Hill |
| 1955 | R.O. Chalmers | 1973 | K. Rankama |
| 1957 | A.H. Voisey | 1975 | K.S.W. Campbell |
| 1959 | D.E. Thomas | 1977 | J.F.G. Wilkinson |
| 1961 | J.A. Dulhunty | 1979 | G.H. Taylor |
| 1965 | A.A. Opik | | |

AWARDS OF THE SOCIETY'S MEDAL AND MONEY PRIZE

Money Prize of £25

| | | | |
|---|---|---|---|
| 1882 | John Fraser | 1882 | Andrew Ross |

The Society's Medal

The Society's Medal with a money prize of £25 was awarded for published papers up to 1896. After 1943 the Medal only was awarded to a member of the Society for meritorious contributions to the advancement of science, including administration and organization of scientific endeavour and for services to the Society.

| | | | |
|---|---|---|---|
| 1884 | W.E. Abbott | 1959 | R.C.L. Bosworth |
| 1886 | S.H. Cox | 1958 | F.R. Morrison |
| 1887 | J. Seaver | 1959 | Ida A. Brown |
| 1888 | Rev. J.E. Tenison-Woods | 1960 | T. Griffith Taylor |
| 1889 | T. Whitelegge | 1961 | A. Bolliger |
| 1889 | Rev. J. Mathew | 1962 | H.W. Wood |
| 1891 | Rev. J. Milne Curran | 1963 | R.S. Nyholm |
| 1892 | A.G. Hamilton | 1964 | F.D. McCarthy |
| 1894 | J.V. De Coque | 1965 | F. Lions |
| 1894 | R.H. Mathews | 1966 | H.A.J. Donegan |
| 1895 | C.J. Martin | 1967 | A.F.A. Harper |
| 1896 | Rev. J. Milne Curran | 1968 | H.H.G. McKern |
| | | 1969 | R.J.W. Le Fevre |
| 1943 | E. Cheel | 1970 | J.A. Dulhunty |
| 1948 | W.L. Waterhouse | 1971 | J.L. Griffiths |
| 1949 | A.P. Elkin | 1972 | W.H.G. Poggendorff |
| 1950 | O.U. Vonwiller | 1973 | R.L. Stanton |
| 1951 | A.R. Penfold | 1975 | W.H. Robertson |
| 1953 | A.B. Walkom | 1976 | E.K. Chaffer |
| 1954 | D.P. Mellor | 1977 | J.W. Humphries |
| 1955 | W.G. Woolnough | 1978 | M.J. Puttock |
| 1956 | W.R. Browne | 1979 | A.A. Day |

AWARDS OF THE JAMES COOK MEDAL

The James Cook Medal is awarded for outstanding contributions to Science and human welfare in and for the Southern Hemisphere.

| | | | |
|---|---|---|---|
| 1947 | The Rt. Hon. J.C. Smuts | 1961 | Sir John Eccles |
| 1948 | B.A. Houssay | 1964 | M.R. Lemberg |
| 1950 | Sir Neil H. Fairley | 1965 | John Gunther |
| 1951 | Sir Norman McAlister Gregg | 1966 | Sir William Hudson |
| 1952 | W.L. Waterhouse | 1969 | Lord Casey of Berwick |
| 1953 | Sir David Rivett | 1974 | Sir Marcus L. Oliphant |
| 1954 | Sir Frank M. Burnet | 1975 | A. Walsh |
| 1955 | A.P. Elkin | 1977 | I.A. Watson |
| 1956 | Sir Ian Clunies Ross | 1978 | Sir Lawrence J. Wackett |
| 1959 | Albert Schweitzer | | |

THE EDGEWORTH DAVID MEDAL

The Edgeworth David Medal is awarded for distinguished contributions by young scientists, under the age of 35 years for work done mainly in Australia or its territories or contributing to the advancement of Australian science.

| | | | |
|---|---|---|---|
| 1948 | R.G. Giovanelli (Astrophysics) | 1950 | Catherine H. Berndt (Anthropology) |
| 1948 | E. Ritchie (Organic Chemistry) | 1951 | J.G. Bolton (Radio Astronomy) |
| 1949 | T.B. Kiely (Plant Pathology) | 1952 | A.B. Wardrop (Botany) |
| 1950 | R.M. Berndt (Anthropology) | 1954 | E.S. Barnes (Mathematics) |

THE EDGEWORTH DAVID MEDAL (Cont.)

| | | | |
|---|---|---|---|
| 1955 | H.B.S. Womersley (Botany) | 1969 | B.W. Ninham (Physics) |
| 1957 | J.M. Cowley (Chemical Physics) | 1970 | D.A. Buckingham (Inorganic Chemistry) |
| 1957 | J.P. Wild (Radio Astronomy) | 1971 | W.F. Budd (Glaciology) |
| 1958 | P.I. Korner (Physiology) | 1972 | D.H. Napper (Physical Chemistry) |
| 1960 | R.D. Brown (Chemistry) | 1972 | J. Stone (Physiology |
| 1961 | R.O. Slatyer (Climatology) | 1973 | C.D. Osmond (Plant Biology |
| 1962 | R.F. Isbell (Soil Science) | 1974 | A.W. Snyder (Physics) |
| 1963 | W.H. Fletcher (Physics) | 1975 | F.J. Ballard (Biochemistry) |
| 1964 | M.E. Holman (Physiology) | 1976 | R.H. Street (Mathematics) |
| 1965 | J.L. Dillon (Agricultural Economics) | 1977 | R.A. Antonia (Mechanical Engineering) |
| 1966 | R,I. Tanner (Mech. Engineering) | 1978 | T.W. Cole (Astronomy) |
| 1967 | D.H. Green (Geology) | 1978 | M.G. Clark (Physiology) |
| 1967 | W.J. Peacock (Botany) | 1979 | G.C. Goodwin (Electrical Engineering) |
| 1968 | R.M. May (Physics) | | |

THE WALTER BURFITT PRIZE

The Walter Burfitt Prize is awarded at intervals of three years to the worker in pure or applied science, resident in Australia or New Zealand, whose papers and other contributions published during the past six years are deemed of the highest scientific merit. It was established as a result of generous gifts to the Society of Dr. and Mrs. W.F. Burfitt.

| | | | |
|---|---|---|---|
| 1929 | N.D. Royle (Medicine) | 1956 | J.C. Eccles (Medicine) |
| 1932 | C.H. Kellaway (Medicine) | 1959 | F.J. Fenner (Microbiology) |
| 1935 | V.A. Bailey (Physics) | 1962 | M.F. Glaessner (palaeontology) |
| 1938 | F.M. Burnet (Medicine) | 1965 | C.A. Fleming (Micropalaeontology) |
| 1941 | F.W. Whitehouse (Geology) | 1968 | L.E. Lyons (Chemistry) |
| 1944 | H.L. Kesteven (Medicine) | 1971 | M.R. Lemberg (Medicine) |
| 1947 | J.C. Jaeger (Mathematics) | 1974 | B.J. Robinson (Radiophysics) |
| 1950 | D.F. Martyn (Ionospheric Physics) | 1977 | A. Kerr (Plant Pathology) |
| 1953 | K.E. Bullen (Geophysics) | | |

LIVERSIDGE RESEARCH LECTURESHIP

The lectureship is awarded at intervals of two years for the purpose of encouragement of research in Chemistry. It was established under the terms of a bequest to the Society by Professor Archibald Liversidge. The lectures are published in the Journal.

| | | | |
|---|---|---|---|
| 1931 | H. Hey | 1958 | A.D. Wadsley |
| 1933 | W.J. Young | 1960 | R.J.W. Le Fevr |
| 1940 | G.J. Burrows | 1962 | D.O. Jordan |
| 1942 | J.S. Anderson | 1964 | A. Albert |
| 1944 | F.P. Bowden | 1966 | L.E. Lyons |
| 1946 | L.H. Briggs | 1968 | R.D. Brown |
| 1948 | I. Lauder | 1970 | G.W.K. Cavill |
| 1950 | Hedley R. Marston | 1974 | A.J. Birch |
| 1952 | A.L.G. Rees | 1976 | R.L. Martin |
| 1954 | M.R. Lembert | 1978 | H.C. Freeman |
| 1956 | G.M. Badger | 1980 | S.R. Johns |

POLLOCK MEMORIAL LECTURES

The Pollock Memorial Lectureship is sponsored by the University of Sydney and the Royal Society of N.S.W. in memory of Professor J.A. Pollock.

| | | | |
|---|---|---|---|
| 1949 | T.M. Cherry | 1965 | F. Seitz |
| 1952 | H.S.W. Massey | 1969 | A.R. Sandage |
| 1955 | R. v. d. R. Woolley | 1972 | L. Schwartz |
| 1959 | Sir Harold Jeffreys | 1975 | J. Tuzo Wilson |
| 1962 | F. Hoyle | 1978 | R.N. Bracewell |

ARCHIBALD D. OLLE PRIZE

The Archibald D. Olle Prize is awarded by the Council to the member of the Society who has submitted the best paper during the year. It was established under the terms of a bequest by Mrs. A.D. Olle.

| | | | |
|---|---|---|---|
| 1956 | R.L. Stanton | 1961 | V.A. Bailey |
| 1958 | A. Reichel | 1962 | J.C. Standard |
| 1959 | G. Bosson | 1964 | J.L. Griffith |
| 1960 | H.G. Golding | 1964 | J. Roberts |

ARCHIBALD D. OLLE PRIZE (Cont.)

| | | | |
|---|---|---|---|
| 1966 | R.A. Binns | 1974 | D.R. Gray |
| 1967 | J.R. Conolly | 1978 | D.S. King |
| 1970 | B.B. Guy | 1979 | R.J. Korsch |

# FINANCIAL STATEMENTS FOR 1979

## AUDITOR'S REPORT TO THE MEMBERS

In our opionion:

(a) the attached Balance Sheet and Income and Expenditure Account are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1979 and of the results of the Society for the year ended on at date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provision of those Rules.

WYLIE & PUTTOCK
Chartered Accountants.

By ALAN M. PUTTOCK
Registered under the Public Accountants
Registration Act, 1945 as amended.

## BALANCE SHEET as at 31/12/79

| | | | | |
|---|---|---|---|---|
| | RESERVES | | | |
| 7199.57 | Library Reserve (note 2(i)) | | | 7299.57 |
| 416991.00 | Resumption Reserve (note 2(ii)) | | | 416991.00 |
| 2378.39 | LIBRARY FUND (note 2(iii)) | | | 2346.30 |
| 12912.84 | TRUST FUNDS (note 5) | | | 13403.11 |
| 73307.24 | ACCUMULATED FUNDS | | | 76357.21 |
| 512789.04 | TOTAL RESERVES & FUNDS | | | 516397.19 |
| | Represented by: | | | |
| | CURRENT ASSETS | | | |
| 28.14 | Petty Cash Imprest | | 49.90 | |
| 1329.22 | Debtors for Subscriptions | 1177.88 | | |
| 1329.22 | Less Provision For Doubtful Debts | 1177.88 | | |
| 3220.67 | Other Debtors & Prepayments | | 2723.82 | |
| 3820.39 | Interest Bearing Deposit | | 4102.37 | |
| 5574.83 | Cash at Bank | | 7878.22 | |
| 12644.03 | | | | 14754.31 |
| | Less: CURRENT LIABILITIES | | | |
| 7614.55 | Sundry Creditors & Accruals | | 8305.45 | |
| 13.67 | Life Members Subscriptions - Current Portion | | 19.37 | |
| 124.69 | Membership Subscriptions Paid in Advance | | 121.00 | |
| 1287.60 | Subcriptions to Journal Paid in Advance | | 1586.89 | |
| 9040.51 | | | | 10032.71 |
| 3603.52 | NET CURRENT ASSETS | | | 4721.60 |
| | Add: FIXED ASSETS | | | |
| 8146.66 | Furniture, Office Equipment, etc.- at cost less Depreciation | | 7292.66 | |
| 13600.00 | Library - 1936 Valuation | | 13600.00 | |
| 11.00 | Pictures - at cost less Depreciation | | 10.00 | |
| 21757.66 | | | | 20902.66 |
| 25361.18 | | | | 25624.26 |

BALANCE SHEET (Continued)

| | | | |
|---|---|---|---|
| | Add: INVESTMENTS | | |
| | Commonwealth Bonds & Inscribed | | |
| 27580.00 | Stock | 30980.00 | |
| 40000.00 | Loans on Mortgage | 40000.00 | |
| 67580.00 | | | 70980.00 |
| | Add: ASSOCIATED CORPORATIONS (note 3) | | |
| 1.00 | Shares - at Cost | 1.00 | |
| 419994.61 | Advances & Loans - Unsecured | 419994.61 | |
| 419995.61 | | | 419995.61 |
| 512936.79 | | | 516599.87 |
| | Less: NON-CURRENT LIABILITIES | | |
| | Life Members Subscriptions - | | |
| 147.75 | Non-Current Portion | | 202.68 |
| 512789.04 | NET ASSETS | | 516397.19 |

D.H. NAPPER President

A.A. DAY Honorary Treasurer

STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31 December 1979

| | | | |
|---|---|---|---|
| 5520.69 | DEFICIT for year | | 791.53 |
| | Donations & Interest to | | |
| 6420.64 | Library Fund | | 323.02 |
| | Proceeds Estate Late Dr. J. F. | | |
| 146.00 | Codrington | | 3486.39 |
| 6262.11 | Transfer from Library Fund | | 355.11 |
| | Accumulated Funds-Beginning of | | |
| 76828.82 | Year | | 73307.24 |
| 84136.88 | AVAILABLE FOR APPROPRIATION | | 76680.23 |
| 6420.64 | Transfer to Library Fund | 323.02 | |
| | Payment for Provision of | | |
| | Library Facilities (Note | | |
| 4409.00 | 1(c)) | | |
| 10829.64 | | | 323.02 |
| 73307.24 | ACCUMULATED FUNDS-Current Year | | 76357.21 |

NOTES TO AND FORMING PART OF THE ACCOUNTS
for the year ended 31st December, 1979

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1979. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

| | |
|---|---|
| Furniture | 7.5% |
| Office Equipment | 15.0% |

(b) Library Fund

During the 1978 year an amount was transfered from the Library Fund to Accumulated Funds as a contribution to the cost of printing & mailing those copies of the Journal & Proceedings involved in the exchange programme whereby the publications of other Societies are aquired for the Library. This procedure was not adopted in the current year.

(c) Library Facilities

Certain donations to the Society's Library Fund have been paid to Science House Pty Limited (see also note 3) towards the cost of providing library facilities for the Society. Such payments represent donations specifically designated by the donor as being for that purpose.

2. MOVEMENTS IN PROVISIONS AND RESERVES

(i) Library Reserve

| | 1978 $ | 1979 $ |
|---|---|---|
| Balance at 1st January | 7200 | 7200 |
| Add | | |
| Sale of Books | - | 100 |
| Balance at 31st December | $7200 | $7300 |

(ii) Resumption Reserve

| | 1978 $ | 1979 $ |
|---|---|---|
| Balance at 1st January | 416991 | 416991 |
| Less | | |
| Movements | - | - |
| Balance at 31st December | $416991 | $416991 |
| Represented by: | | |
| Shares in associated corporation | 1 | 1 |
| Loans to associated corporation | 416990 | 416990 |
| | $416991 | $416991 |

(iii) Library Fund

| | 1978 $ | 1978 $ | 1979 $ | 1979 $ |
|---|---|---|---|---|
| Balance at 1st January | | 2220 | | 2378 |
| Add Donations and bank interest | | 6421 | | 323 |
| | | 8641 | | 2701 |
| Less Library purchases | 856 | | 355 | |
| Library fittings & equipment | 998 | | - | |
| Paid re library facilities | 4409 | | - | |
| | | 6263 | | 355 |
| Balance at 31st December | | $2378 | | $2346 |
| Represented by: | | | | |
| Cash at bank | | 606 | | 51 |
| Commonwealth Bonds | | 2300 | | 2300 |
| Owing to general funds | | (528) | | (5) |
| | | $2378 | | $2346 |

3. ASSOCIATED CORPORATIONS

The Society has entered into a joint venture with the Linnean Society for the establishment and operation of a Science Centre for New South Wales and to facilitate this, a company, Science House Pty. Limited, has been formed in which each Society has 50% interest.
Advances and loans to the company have been on an interest free basis repayable at call. No material repayments are anticipated prior to 31st December, 1980

| | 1978 $ | 1979 $ |
|---|---|---|
| Balance at 1st January, 1979 | 419995 | 419995 |
| Less Movements | - | |
| Balance at 31st December 1979 | $419995 | $419995 |
| Representing: | | |
| Resumption reserve | 416991 | 416991 |
| Accumulated funds | 3004 | 3004 |
| | $419995 | $419995 |

4. CONTINGENT LIABILITY

The printing costs of the current year volume of the Society's Journal & Proceedings does not include $1541 which the printer expects to receive by way of "Book Bounty" from the Commonwealth Government. In the event of the Book Bounty not being received by the printer, the Society's liabilities would be increased by an equivalent amount.

5. TRUST FUNDS

| | 1978 $ | Clarke Memorial $ | Walter Burfitt Prize $ | Liversidge Bequest $ | Olle Bequest $ | Total $ |
|---|---|---|---|---|---|---|
| **Capital** | | | | | | |
| Balance at 1st January | 11100 | 4800 | 3000 | 2000 | 1300 | 11100 |
| Capitalisation of accumulated revenue | - | - | - | - | - | - |
| Balance at 31st December | $11100 | $4800 | $3000 | $2000 | $1300 | $11100 |
| **Revenue** | | | | | | |
| Revenue income for period | 1224 | 534 | 334 | 223 | 287 | 1378 |
| Less Expenditure | 230 | 278 | - | 526 | 84 | 888 |
| | 994 | 256 | 334 | (303) | 203 | 490 |
| Add Balance from 1978 | 819 | 446 | 458 | 412 | 497 | 1813 |
| | 1813 | 702 | 792 | 109 | 700 | 2303 |
| Less Capitalisation | - | - | - | - | - | - |
| Total Revenue | $1813 | $702 | $792 | $109 | $700 | $2303 |
| Total Trust Funds | $12913 | $5502 | $3792 | $2109 | $2000 | $13403 |

FUNDS STATEMENT FOR THE YEAR ENDED 31ST DECEMBER 1979

| | 1978 $ | 1978 $ | 1979 $ | 1979 $ |
|---|---|---|---|---|
| SOURCE OF FUNDS | | | | |
| Operating deficit for the year | | | (791) | |
| Add: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | - | | 855 | |
| Provision for doubtful debts | - | | 610 | |
| Funds derived from operations | | - | | 674 |
| Donations and interest to library fund | | 6420 | | 323 |
| Library sales | | - | | 100 |
| Trust fund income | | 1224 | | 1378 |
| Reduction in working funds | | 2875 | | |
| Life membership subscriptions | | 90 | | 80 |
| Proceeds Estate Late Dr. J. F. Codrington | | 146 | | 3486 |
| | | $10755 | | $6041 |
| APPLICATION OF FUNDS | | | | |
| Operating deficit for the year | 5521 | | | |
| Less: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | 694 | | - | |
| Provision for doubtful debts | 730 | | - | |
| Funds applied to operations | | 4097 | | |
| Purchase of furniture & equipment | | 998 | | |
| Reclassification of life members subscriptions in advance | | 21 | | 25 |
| Increase in investments | | 1000 | | 3400 |
| Trust fund expenses | | 230 | | 888 |
| Payment for provision of library facilities | | 4409 | | |
| Increase in working funds | | - | | 1728 |
| | | $10755 | | $6041 |

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31 December 1979

| | | | | |
|---|---|---|---|---|
| | INCOME | | | |
| 6588.50 | Membership Subscriptions - Ordinary | | | 7252.00 |
| 13.67 | Membership Subscriptions - Life Members | | | 19.37 |
| 73.80 | Application Fees | | | 105.60 |
| 6675.97 | | | | 7376.97 |
| 3061.59 | Subscriptions to Journal | | | 3356.29 |
| - | Government Subsidy | | | 2000.00 |
| 9737.56 | Total Membership & Journal Income | | | 12733.26 |
| 6101.29 | Interest Received | | | 6678.40 |
| 578.09 | Sale of Back Numbers | | | 66.50 |
| 119.70 | Sale of Other Publications | | | 84.00 |
| - | Donations - General | | | 3.00 |
| 447.51 | Summer School Surplus | | | 559.40 |
| 136.40 | Other Income | | | 30.00 |
| 17120.55 | | | | 20154.56 |
| | Less: EXPENSES | | | |
| 710.00 | Accountancy Fees | | 726.00 | |
| 54.00 | Advertising | | 33.00 | |
| 213.10 | Annual Social | | 22.75 | |
| 350.00 | Audit Fees | | 374.00 | |
| - | Branches of the Society | | 100.00 | |
| 120.00 | Cleaning | | 132.50 | |
| 694.00 | Depreciation | | 855.00 | |
| 237.07 | Electric Light & Power | | 254.64 | |
| 156.39 | Entertainment Expenses | | 224.29 | |
| 147.56 | Insurance | | 531.16 | |
| | Journal Publication Costs | | | |
| 4740.10 | Printing - Current Year Volume (note 4) | 3941.46 | | |
| 1194.85 | Wrapping & Postage | 714.58 | | |
| | | | 4656.04 | |
| 246.05 | Legal Costs | | - | |
| 865.77 | Library Purchases | | 364.94 | |
| 13.50 | Library Relocation | | - | |
| 721.22 | Miscellaneous Expenses | | 616.83 | |
| 1243.40 | Newsletter Printing & Distribution | | 1214.62 | |
| 322.62 | Postage | | 304.70 | |
| 440.66 | Printing & Stationery - General | | 160.27 | |
| 729.96 | Provision for Doubtful Debts | | 609.66 | |
| 2932.22 | Rent | | 2781.28 | |
| 71.35 | Repairs & Maintenance | | 168.50 | |
| 245.75 | Reprints - Loss on Sale | | 185.90 | |
| 5449.33 | Salaries | | 6314.94 | |
| 519.49 | Secretarial Services | | 77.95 | |
| 222.85 | Telephone | | 237.12 | |
| 22641.24 | | | | 20946.09 |
| 5520.69 | DEFICIT for the year | | | 791.53 |

# NOTICE TO AUTHORS

"Style Guide to Authors" is available from the ırary Secretary, Royal Society of New South ·s, 35 Clarence Street, Sydney, N.S.W. 2000, and ding authors *must* read the guide before preparing manuscript for review. The more important rements are summarized below.

## ERAL

ınuscripts should be addressed to the Honorary tary (address given above).

ınuscripts submitted by a non-member must be ıunicated by a member of the Society.

ch manuscript will be scrutinised by the Publica- Committee before being sent to an independent ·e who will advise the Council of the Society on cceptability of the paper. In the event of rejection, scripts may be sent to two other referees.

ɔers, other than those specially invited by Council, only be considered if the content is substantially material which has not been published previously, not been submitted concurrently elsewhere, nor ‹ely to be published substantially in the same elsewhere. Well-known work and experimental dure should be referred to only briefly, and sive reviews and historical surveys should, as a be avoided. Letters to the Editor and short notes also be submitted for publication.

iginal papers or illustrations published in the ıal and Proceedings of the Society may be duced only with the permission of the author of the Council of the Society; the usual ɔwledgments must be made.

set printing with "Typeset-it-Yourself" preparation master manuscript suitable for photography is used ː production of the Journal. Authors will be supplied a set of special format paper. An IBM Selectric Ball) typewriter with ADJUTANT 12 typeface be used. Biological and reference material are n in *Light Italic*. Symbol 12 has most type red for mathematical expressions and formulae. iled instructions for the typist are included in the Guide.

## SENTATION OF INITIAL MANUSCRIPT REVIEW

pescripts should be submitted on heavy bond A4 r. A second copy of both text and illustrations is red for office use. This may be a clear carbon ɔhotographic copy. Manuscripts, including the act, captions for illustrations and tables, acknow- nents and references should be typed in double ng on one side of the paper only.

anuscripts should be arranged in the following r: title; name(s) of author(s); abstract; introduction; text; conclusions and/or summary; acknowledg- s; references; appendices; name of Institution/ nisation where work carried out/or private address pplicable; date manuscript received by the Society. ble of contents should also accompany the paper he guidance of the Editor.

elling follows "The Concise Oxford Dictionary".

e Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the Australian Code of Stratigraphic Nomenclature (revised fourth edition) and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra. The letter of approval should be submitted with the manuscript.

*Abstract.* A brief but fully informative abstract must be provided.

*Tables* should be adjusted for size to fit the format paper of the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

*Illustrations.* When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to $\frac{1}{2}$ size) must be clearly stated.

*Note:* There is a reduction of 30% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, large figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stippling should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diagrams must be given in bar form.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper (no negative is required).

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

*References* are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow the preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Abbreviations of titles of periodicals shall be in accordance with the International Standard Organization IS04 "International Code for the Abbreviation of Titles of Periodicals" and International Standard Organization IS0833 "International List of Periodical Title Word Abbreviations" and as amended.

*Appendices* should be placed at the end of the paper, be numbered in Arabic numerals, have a caption and be referred to in the text.

*Reprints.* An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

# Contents

## VOLUME 113, PART 3



## VOLUME 113, PART 4



Publicity Press Ltd., 29-31 Meagher Street, Chippendale, Sydney.

# Journal and Proceedings of the Royal Society of New South Wales

VOLUME 114 1981 PARTS 1 and 2
(Nos. 319 and 320)

Published by the Society
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ISSN 0035 - 9173

# THE ROYAL SOCIETY OF NEW SOUTH WALES



Address:— Royal Society of New South Wales,
35 Clarence Street,
Sydney, NSW, 2000,
Australia.

## THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library; awards of Prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special Meetings are held for the Pollock Memorial Lecture in Physics and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology.

Membership is open to any interested person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personnally known. Membership categories are: Ordinary Members, Absentee Members and Associate Members. Annual Membership fee may be ascertained from the Society's Office.

Subscriptions to the Journal are welcomed. The current subscription rate may be ascertained from the Society's Office.

The Society welcomes manuscripts of research (and occasional review articles) in all branches of science, art, literature and philosophy, for publication in the Journal and Proceedings.

Manuscripts will be accepted from both members and non-members, though those from the latter should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the above address.

Journal and Proceedings, Royal Society of New South Wales, Vol. 114, pp. 1-5, 1981
ISSN 0035-9173

# Precise Observations of Minor Planets at Sydney Observatory During 1980

N. R. Lomb

ABSTRACT. Positions of 2 Pallas, 3 Juno, 6 Hebe, 7 Iris, 18 Melpomene, 40 Harmonia, 51 Nemausa and 532 Herculina obtained with the 23 cm camera are given.

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1980 are given here. The methods of observation were described in the first paper (Robertson 1958). All the plates were taken with the 23 cm camera (scale 116" to the millimetre). Four exposures were taken on each plate, except on some plates of 18 Melpomene, 40 Harmonia, 51 Nemausa and 532 Herculina. The number of exposures on each plate is indicated in Table 1.

In Table 1 are given the means of the positions for all the exposures using all six reference stars at the mean of the exposure times. The result for the first pair of images was compared with that for the last two by adding the motion computed from the ephemeris for the plates with four exposures. The r.m.s. differences were $0^{s}.010$ Sec $\delta$ in right ascension and $0''.22$ in declination.

No correction has been applied for aberration, light time or parallax, but the factors give the parallax correction when divided by the distance. The column headed "O-C" gives the differences between the measured positions (corrected for parallax) and the position computed from the ephemerides supplied by the Institute for Theoretical Astronomy in Leningrad. The ephemeris for 51 Nemausa was obtained from L.K. Kristensen (University of Aarhus, Denmark).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table 2 gives for each observation the positions of the reference stars and the six star dependences. The reference star positions were converted to standard coordinates for the calculation of six star dependences. The columns headed "R.A." and "Dec." give the seconds of time and arc with the proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Star" gives the number of the star in the SAO catalogue or the zone and number of the star in the AGK3 catalogue. The column headed "Vol." gives the volume of the SAO or AGK3 in which the star is listed. The first column gives a serial number which cross-references Table 1 and Table 2 and also the catalogue from which the reference stars were taken.

All plates were reduced by both the method of dependences and by first order plate constants using the same six reference stars. Equal results were obtained in each case, as could be expected due to the formal identity of the two methods. The r.m.s. residuals of the reference stars were obtained by taking for each star the mean residual from the plate constants fitted to the first and last pairs of images, summing the squares of these residuals in right ascension and declination for all stars on all plates with four exposures and dividing the result by the appropriate number of degrees of freedom. For AGK3 stars the r.m.s. residual was $0''.37$ (9 plates) while for SAO stars it was $0''.79$ (21 plates).

Using six star dependences instead of two sets of three star dependences, as had been employed in reducing observations from years previous to 1978, has the disadvantage that a direct measure of the uncertainties in the measured positions is no longer available and the uncertainties have to be found by indirect means. The method used was described in a previous paper (Lomb 1980). The standard errors calculated in this way are listed in Table 3.

The plates were measured by Mrs J. Close, Miss D. Teale, Miss J. Manson and Miss R. Skeers. The observers at the telescope were D.S. King (K), N.R. Lomb (L), W.H. Robertson (R) and K.P. Sims (S).

REFERENCES

Robertson, W.H., 1958. Precise observations of minor planets at Sydney Observatory during 1955 and 1956. *J. Roy. Soc. N.S.W. 92, 18-23 Sydney Observatory Papers No. 33.*

Lomb, N.R., 1980. Precise observations of minor planets at Sydney Observatory during 1979. *J. Roy. Soc. N.S.W. 113, 1-6 Sydney Observatory Papers No. 88.*

TABLE 1

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O − C s | " | No. of Exp. | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 Pallas 1980 U.T. | | | | | | | | |
| 1714 | Aug. 12.79088 | 02 29 03.553 | −02 23 12.04 | −0.003 | −4.58 | −0.085 | −0.22 | 4 | L |
| 1715 | Aug. 18.77045 | 02 32 53.800 | −03 29 19.07 | −0.024 | −4.44 | −0.119 | +0.06 | 4 | R |
| 1716 | Sep. 09.71955 | 02 41 01.463 | −08 40 38.09 | −0.013 | −3.73 | −0.138 | +0.02 | 4 | S |
| 1717 | Sep. 15.70930 | 02 41 21.100 | −10 22 12.07 | +0.006 | −3.50 | −0.107 | −0.06 | 4 | L |
| 1718 | Oct. 15.62331 | 02 30 05.219 | −19 19 55.64 | +0.018 | −2.20 | −0.067 | +0.47 | 4 | S |
| 1719 | Oct. 28.57226 | 02 20 09.339 | −22 33 48.62 | −0.010 | −1.71 | −0.040 | +0.46 | 4 | K |
| 1720 | Nov. 10.51908 | 02 09 40.687 | −24 49 10.44 | −0.046 | −1.39 | −0.070 | +0.36 | 4 | R |
| 1721 | Dec. 08.44726 | 01 55 09.488 | −25 55 09.05 | +0.004 | −1.21 | −0.037 | +0.69 | 4 | R |
| | 3 Juno 1980 U.T. | | | | | | | | |
| 1722 | Feb. 11.49123 | 07 02 35.516 | +06 28 12.75 | +0.023 | −5.66 | −0.021 | −0.26 | 4 | S |
| 1723 | Feb. 19.46980 | 07 01 27.983 | +07 48 49.13 | +0.027 | −5.81 | −0.037 | −0.60 | 4 | K |
| 1724 | Mar. 17.41383 | 07 11 43.165 | +11 38 39.51 | +0.060 | −6.23 | −0.020 | −0.15 | 4 | S |
| | 6 HEBE 1980 U.T. | | | | | | | | |
| 1725 | Sep. 09.75581 | 03 51 18.719 | −00 11 15.96 | −0.051 | −4.86 | −0.008 | +0.19 | 4 | S |
| 1726 | Sep. 15.76100 | 03 56 59.573 | −01 01 31.00 | +0.003 | −4.75 | −0.005 | +0.19 | 4 | L |
| 1727 | Oct. 08.69552 | 04 07 52.470 | −04 46 26.39 | −0.028 | −4.26 | −0.054 | +0.43 | 4 | R |
| 1728 | Oct. 15.70191 | 04 07 23.086 | −05 56 50.51 | +0.052 | −4.10 | −0.005 | +0.09 | 4 | S |
| 1729 | Oct. 29.63978 | 04 01 17.254 | −07 57 12.13 | −0.009 | −3.83 | +0.023 | +0.16 | 4 | K |
| 1730 | Nov. 10.59985 | 03 51 49.073 | −08 59 50.84 | −0.011 | −3.68 | +0.004 | +0.23 | 4 | R |
| 1731 | Nov. 27.54868 | 03 36 20.960 | −08 54 28.12 | +0.008 | −3.70 | −0.035 | +0.81 | 4 | S |
| 1732 | Dec. 09.49897 | 03 27 29.377 | −07 42 55.06 | −0.026 | −3.86 | +0.030 | +0.16 | 4 | R |
| | 7 IRIS 1980 U.T. | | | | | | | | |
| 1733 | Oct. 28.45027 | 23 21 15.766 | +05 52 09.49 | −0.004 | −5.61 | +0.143 | +1.38 | 4 | K |
| 1734 | Nov. 06.43572 | 23 23 11.748 | +05 12 13.27 | +0.023 | −5.53 | +0.166 | +1.32 | 4 | R |
| 1735 | Nov. 11.42080 | 23 25 31.441 | +04 57 34.52 | +0.014 | −5.51 | +0.135 | +1.36 | 4 | L |
| | 18 MELPOMENE 1980 U.T. | | | | | | | | |
| 1736 | Mar. 17.67743 | 13 58 20.380 | −00 24 02.04 | +0.004 | −4.80 | −0.007 | +0.14 | 4 | R |
| 1737 | Apr. 22.57164 | 13 29 18.937 | +04 15 00.77 | +0.043 | −5.38 | +0.037 | −0.16 | 2 | L |
| 1738 | May 12.50371 | 13 14 03.648 | +05 38 20.38 | +0.035 | −5.55 | +0.023 | −0.07 | 2 | S |
| 1739 | June 05.42549 | 13 06 11.673 | +05 31 49.57 | +0.012 | −5.53 | −0.029 | +0.16 | 2 | R |
| | 40 HARMONIA 1980 U.T. | | | | | | | | |
| 1740 | July 10.79617 | 00 27 52.438 | −02 18 26.20 | −0.006 | −4.60 | −0.095 | +0.37 | 2 | L |
| 1741 | July 17.79577 | 00 33 52.923 | −02 00 29.82 | +0.039 | −4.64 | −0.043 | +0.24 | 2 | R |
| 1742 | Aug. 05.73687 | 00 44 29.263 | −01 53 08.85 | −0.005 | −4.65 | −0.034 | +0.18 | 4 | K |
| 1743 | Aug. 11.72962 | 00 45 49.740 | −02 04 24.62 | +0.020 | −4.63 | −0.033 | +0.35 | 4 | L |
| 1744 | Aug. 18.70216 | 00 46 01.193 | −02 25 52.86 | −0.006 | −4.58 | −0.034 | +0.68 | 4 | R |
| 1745 | Sep. 08.64623 | 00 37 40.331 | −04 16 09.96 | +0.016 | −4.34 | −0.065 | −0.19 | 4 | S |
| 1746 | Oct. 13.54299 | 00 07 12.822 | −07 31 41.65 | +0.058 | −3.90 | −0.001 | −0.61 | 4 | S |
| 1747 | Oct. 28.47794 | 23 58 17.368 | −07 50 08.09 | +0.002 | −3.85 | −0.041 | +0.07 | 4 | K |
| 1748 | Nov. 11.44916 | 23 55 49.942 | −07 20 27.22 | +0.037 | −3.92 | −0.053 | −0.07 | 4 | R |

TABLE 1 (Cont.)

POSITIONS OF MINOR PLANETS

| No. | | R.A. (1950.0) h m s | Dec. (1950.0) ° ' " | Parallax Factors s | " | O – C s | " | No. of Exp. | |
|---|---|---|---|---|---|---|---|---|---|
| | 51 NEMAUSA 1980 U.T. | | | | | | | | |
| 1749 | Oct. 08.73880 | 04 58 26.591 | +10 59 00.41 | -0.003 | -6.18 | +0.005 | -0.55 | 2 | R |
| 1750 | Nov. 12.62971 | 04 47 51.692 | +07 15 56.02 | -0.022 | -5.76 | -0.010 | +0.07 | 2 | R |
| 1751 | Nov. 27.58393 | 04.34 11.255 | +05 57 20.80 | -0.008 | -5.61 | -0.019 | -0.16 | 2 | S |
| 1752 | Dec. 09.54420 | 04 22 14.038 | +05 19 34.82 | -0.004 | -5.54 | -0.023 | -0.06 | 2 | R |
| | 532 HERCULINA 1980 U.T. | | | | | | | | |
| 1753 | Oct. 15.66585 | 02 50 51.249 | -07 12 33.94 | +0.103 | -3.95 | +0.009 | +0.21 | 2 | S |
| 1754 | Nov. 10.54646 | 02 29 19.865 | -08 33 03.71 | +0.001 | -3.75 | -0.036 | +0.50 | 2 | R |
| 1755 | Dec. 09.45154 | 02 10 12.213 | -07 31 50.11 | -0.007 | -3.89 | +0.010 | +0.02 | 2 | R |

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Vol. | Star | Depend. | R.A. | Dec. | No. | Vol. | Star | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1714 | 3 | 129917 | 0.211012 | 05.684 | 25.02 | 1721 | 3 | 167375 | 0.154258 | 32.463 | 15.57 |
| SAO | 3 | 129927 | 0.166340 | 02.612 | 36.20 | SAO | 3 | 167385 | 0.176291 | 08.800 | 23.49 |
| | 3 | 129958 | 0.192436 | 35.876 | 54.52 | | 3 | 167386 | 0.131029 | 13.330 | 35.41 |
| | 3 | 129977 | 0.124965 | 25.721 | 21.67 | | 3 | 167447 | 0.153185 | 31.710 | 28.37 |
| | 3 | 129980 | 0.173886 | 35.191 | 14.03 | | 3 | 167482 | 0.198649 | 25.013 | 27.00 |
| | 3 | 129993 | 0.131361 | 51.283 | 48.22 | | 3 | 167496 | 0.186587 | 17.296 | 28.63 |
| 1715 | 3 | 129970 | 0.213969 | 37.202 | 55.74 | 1722 | 7 | + 6° 855 | 0.171831 | 56.152 | 14.20 |
| SAO | 3 | 129973 | 0.243686 | 46.909 | 34.87 | AGK3 | 7 | + 5° 935 | 0.187013 | 07.030 | 49.82 |
| | 3 | 129993 | 0.170036 | 51.283 | 48.22 | | 7 | + 7° 915 | 0.150441 | 04.889 | 13.41 |
| | 3 | 130005 | 0.194303 | 35.152 | 16.34 | | 7 | + 7° 929 | 0.145209 | 34.910 | 23.39 |
| | 3 | 130044 | 0.086091 | 30.673 | 39.21 | | 7 | + 5° 949 | 0.182826 | 46.879 | 18.01 |
| | 3 | 130051 | 0.091915 | 06.269 | 20.34 | | 7 | + 6° 875 | 0.162681 | 27.538 | 07.65 |
| 1716 | 3 | 130034 | 0.139531 | 29.288 | 01.77 | 1723 | 7 | + 8° 885 | 0.125933 | 58.154 | 46.46 |
| SAO | 3 | 130043 | 0.113609 | 30.511 | 56.55 | AGK3 | 7 | + 7° 907 | 0.168506 | 19.702 | 04.88 |
| | 3 | 130054 | 0.198210 | 35.714 | 25.05 | | 7 | + 7° 914 | 0.228838 | 00.067 | 35.84 |
| | 3 | 130086 | 0.130208 | 32.846 | 15.90 | | 7 | + 8° 901 | 0.095209 | 12.962 | 46.68 |
| | 3 | 130105 | 0.240663 | 04.364 | 13.99 | | 7 | + 8° 912 | 0.156439 | 00.925 | 26.87 |
| | 3 | 130115 | 0.177780 | 02.047 | 12.32 | | 7 | + 7° 929 | 0.225075 | 34.910 | 23.39 |
| 1717 | 3 | 130059 | 0.226672 | 48.277 | 37.04 | 1724 | 6 | +12° 862 | 0.169173 | 44.081 | 38.10 |
| SAO | 3 | 148562 | 0.166118 | 04.746 | 19.74 | AGK3 | 7 | +11° 814 | 0.191425 | 53.763 | 51.50 |
| | 3 | 130086 | 0.219882 | 32.846 | 15.90 | | 7 | +10° 903 | 0.187738 | 17.357 | 00.83 |
| | 3 | 148578 | 0.109973 | 11.753 | 33.29 | | 6 | +12° 871 | 0.144919 | 20.355 | 08.84 |
| | 3 | 148589 | 0.115260 | 12.507 | 55.83 | | 7 | +11° 829 | 0.163109 | 02.106 | 28.89 |
| | 3 | 148592 | 0.162095 | 03.804 | 04.32 | | 7 | +12° 879 | 0.143625 | 10.550 | 01.35 |
| 1718 | 3 | 148410 | 0.220294 | 31.601 | 29.54 | 1725 | 8 | – 0° 407 | 0.178732 | 34.420 | 51.33 |
| SAO | 3 | 148413 | 0.219646 | 47.440 | 37.95 | AGK3 | 8 | – 0° 408 | 0.172368 | 16.912 | 40.63 |
| | 3 | 148458 | 0.165588 | 47.856 | 28.61 | | 8 | – 1° 366 | 0.159501 | 18.228 | 00.53 |
| | 3 | 167884 | 0.160703 | 45.815 | 22.44 | | 8 | + 0° 337 | 0.173397 | 30.250 | 11.51 |
| | 3 | 167911 | 0.130911 | 05.207 | 20.78 | | 8 | + 0° 341 | 0.162751 | 34.019 | 00.25 |
| | 3 | 148516 | 0.102858 | 55.672 | 55.98 | | 8 | – 0° 415 | 0.153252 | 11.101 | 54.07 |
| 1719 | 3 | 167691 | 0.145049 | 55.063 | 57.90 | 1726 | 8 | – 0° 413 | 0.165840 | 40.085 | 11.00 |
| SAO | 3 | 167701 | 0.153855 | 08.145 | 59.34 | AGK3 | 8 | – 1° 367 | 0.157090 | 25.624 | 33.54 |
| | 3 | 167706 | 0.150878 | 33.137 | 45.41 | | 8 | – 1° 375 | 0.159252 | 53.575 | 17.35 |
| | 3 | 167735 | 0.171765 | 11.135 | 17.18 | | 8 | – 0° 420 | 0.174868 | 14.429 | 38.69 |
| | 3 | 167787 | 0.187720 | 57.845 | 32.15 | | 8 | – 0° 427 | 0.174653 | 22.123 | 21.06 |
| | 3 | 167790 | 0.190733 | 05.305 | 39.68 | | 8 | – 1° 382 | 0.168297 | 47.967 | 06.04 |
| 1720 | 3 | 167577 | 0.162088 | 56.195 | 53.38 | 1727 | 3 | 130955 | 0.189745 | 09.985 | 02.99 |
| SAO | 3 | 167585 | 0.159601 | 30.528 | 54.86 | SAO | 3 | 130970 | 0.190780 | 29.793 | 18.18 |
| | 3 | 167615 | 0.169755 | 42.949 | 31.64 | | 3 | 130983 | 0.149258 | 27.551 | 25.31 |
| | 3 | 167640 | 0.163027 | 50.846 | 05.25 | | 3 | 131024 | 0.143497 | 46.367 | 13.50 |
| | 3 | 167644 | 0.172768 | 16.778 | 04.03 | | 3 | 131026 | 0.173347 | 51.749 | 18.60 |
| | 3 | 167675 | 0.172760 | 21.250 | 57.72 | | 3 | 131060 | 0.153374 | 46.422 | 39.48 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Vol. | Star | Depend. | R.A. | Dec. | No. | Vol. | Star | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1728 | 3 | 130937 | 0.140587 | 47.674 | 37.04 | 1739 | 7 | + 5°1801 | 0.170215 | 32.781 | 24.88 |
| SAO | 3 | 130947 | 0.171373 | 23.889 | 01.89 | AGK3 | 7 | + 6°1588 | 0.167608 | 09.095 | 45.56 |
| | 3 | 130979 | 0.189529 | 09.485 | 27.20 | | 8 | + 4°1678 | 0.169778 | 08.358 | 55.56 |
| | 3 | 131007 | 0.140699 | 25.061 | 50.25 | | 7 | + 6°1597 | 0.163114 | 39.923 | 06.69 |
| | 3 | 131029 | 0.162137 | 04.150 | 20.37 | | 8 | + 4°1685 | 0.166071 | 31.777 | 34.73 |
| | 3 | 131052 | 0.195674 | 23.930 | 16.89 | | 7 | + 5°1809 | 0.153214 | 26.568 | 44.46 |
| 1729 | 3 | 130861 | 0.135035 | 49.386 | 54.39 | 1740 | 3 | 128773 | 0.273956 | 21.678 | 28.81 |
| SAO | 3 | 130868 | 0.169849 | 43.197 | 13.64 | SAO | 3 | 128774 | 0.244771 | 54.963 | 21.67 |
| | 3 | 130875 | 0.108315 | 44.728 | 25.45 | | 3 | 128800 | 0.181195 | 15.626 | 41.17 |
| | 3 | 130927 | 0.211422 | 26.829 | 55.20 | | 3 | 128819 | 0.152091 | 33.457 | 37.44 |
| | 3 | 130941 | 0.165711 | 07.444 | 16.93 | | 3 | 128834 | 0.080565 | 09.100 | 15.69 |
| | 3 | 130971 | 0.209668 | 44.768 | 58.99 | | 3 | 128845 | 0.067423 | 59.055 | 29.98 |
| 1730 | 3 | 130771 | 0.182286 | 35.440 | 42.68 | 1741 | 3 | 128804 | 0.150180 | 50.474 | 36.43 |
| SAO | 3 | 130772 | 0.199862 | 38.247 | 13.70 | SAO | 3 | 128819 | 0.189019 | 33.457 | 37.44 |
| | 3 | 130808 | 0.149269 | 58.180 | 47.28 | | 3 | 128834 | 0.140552 | 09.100 | 15.69 |
| | 3 | 149261 | 0.177776 | 36.302 | 36.88 | | 3 | 128871 | 0.197426 | 45.610 | 48.15 |
| | 3 | 130827 | 0.140790 | 39.896 | 11.52 | | 3 | 128883 | 0.145634 | 31.888 | 39.29 |
| | 3 | 130856 | 0.150017 | 58.103 | 25.19 | | 3 | 128889 | 0.177188 | 58.984 | 42.83 |
| 1731 | 3 | 130591 | 0.215304 | 51.707 | 00.96 | 1742 | 3 | 128930 | 0.168880 | 26.650 | 18.14 |
| SAO | 3 | 130612 | 0.187117 | 03.839 | 37.73 | SAO | 3 | 128908 | 0.165457 | 34.344 | 39.10 |
| | 3 | 130619 | 0.182998 | 35.991 | 29.99 | | 3 | 128950 | 0.163694 | 00.448 | 31.05 |
| | 3 | 130651 | 0.153040 | 01.034 | 17.59 | | 3 | 128953 | 0.170296 | 10.291 | 52.68 |
| | 3 | 130666 | 0.140219 | 57.298 | 09.73 | | 3 | 128981 | 0.167643 | 14.298 | 36.65 |
| | 3 | 130681 | 0.121322 | 32.070 | 48.47 | | 3 | 128985 | 0.164030 | 31.439 | 33.95 |
| 1732 | 3 | 130497 | 0.230071 | 29.039 | 21.49 | 1743 | 3 | 128930 | 0.144720 | 26.650 | 18.14 |
| SAO | 3 | 130504 | 0.221694 | 15.747 | 16.75 | SAO | 3 | 128931 | 0.133721 | 30.920 | 07.61 |
| | 3 | 130521 | 0.185325 | 30.146 | 29.70 | | 3 | 128964 | 0.185872 | 36.542 | 45.83 |
| | 3 | 130540 | 0.161474 | 37.634 | 47.98 | | 3 | 128965 | 0.154105 | 46.621 | 42.95 |
| | 3 | 130585 | 0.106063 | 12.537 | 30.53 | | 3 | 128982 | 0.197690 | 17.322 | 16.75 |
| | 3 | 130590 | 0.095374 | 43.163 | 08.98 | | 3 | 128985 | 0.183891 | 31.439 | 33.95 |
| 1733 | 7 | + 5°3362 | 0.160561 | 56.004 | 40.71 | 1744 | 3 | 128930 | 0.130163 | 26.650 | 18.14 |
| AGK3 | 7 | + 6°3182 | 0.140141 | 45.969 | 54.44 | SAO | 3 | 128948 | 0.150474 | 57.803 | 52.53 |
| | 8 | + 4°3138 | 0.188638 | 50.666 | 02.31 | | 3 | 128953 | 0.148074 | 10.291 | 52.68 |
| | 7 | + 6°3189 | 0.151870 | 27.372 | 28.18 | | 3 | 128968 | 0.181707 | 44.491 | 52.95 |
| | 7 | + 5°3377 | 0.193363 | 02.036 | 52.43 | | 3 | 128970 | 0.178777 | 04.117 | 10.13 |
| | 7 | + 6°3190 | 0.165427 | 34.199 | 38.40 | | 3 | 128999 | 0.210806 | 28.985 | 26.83 |
| 1734 | 7 | + 5°3367 | 0.173130 | 30.436 | 54.04 | 1745 | 3 | 128822 | 0.143084 | 51.853 | 10.47 |
| AGK3 | 7 | + 6°3187 | 0.212179 | 48.405 | 34.34 | SAO | 3 | 128859 | 0.122640 | 23.607 | 31.98 |
| | 8 | + 3°3003 | 0.129681 | 57.685 | 46.60 | | 3 | 128879 | 0.245336 | 08.097 | 23.07 |
| | 8 | + 4°3144 | 0.136625 | 47.969 | 31.58 | | 3 | 128883 | 0.100475 | 31.888 | 39.29 |
| | 7 | + 5°3384 | 0.192787 | 59.088 | 30.11 | | 3 | 128922 | 0.147187 | 16.904 | 10.29 |
| | 8 | + 4°3146 | 0.155599 | 40.466 | 12.99 | | 3 | 128927 | 0.241278 | 46.781 | 22.20 |
| 1735 | 8 | + 4°3140 | 0.212969 | 38.864 | 50.46 | 1746 | 3 | 128568 | 0.228655 | 22.938 | 17.03 |
| AGK3 | 7 | + 5°3375 | 0.232854 | 48.971 | 59.46 | SAO | 3 | 128594 | 0.230561 | 06.709 | 59.70 |
| | 8 | + 4°3144 | 0.174473 | 47.969 | 31.58 | | 3 | 128608 | 0.141913 | 12.058 | 14.08 |
| | 7 | + 5°3386 | 0.159357 | 55.650 | 29.74 | | 3 | 128645 | 0.093880 | 46.366 | 14.35 |
| | 7 | + 5°3389 | 0.126970 | 31.951 | 15.55 | | 3 | 128646 | 0.176206 | 48.876 | 46.11 |
| | 8 | + 4°3151 | 0.093377 | 37.840 | 58.23 | | 3 | 128666 | 0.128786 | 08.910 | 03.97 |
| 1736 | 8 | − 0°1882 | 0.131160 | 09.719 | 30.96 | 1747 | 3 | 146999 | 0.204060 | 12.041 | 12.08 |
| AGK3 | 8 | − 0°1884 | 0.135752 | 48.931 | 45.25 | SAO | 3 | 147014 | 0.202077 | 41.113 | 08.61 |
| | 8 | − 1°1802 | 0.165958 | 25.318 | 49.06 | | 3 | 147022 | 0.164116 | 33.164 | 38.50 |
| | 8 | + 0°1698 | 0.161444 | 32.423 | 48.34 | | 3 | 147049 | 0.173168 | 43.575 | 55.33 |
| | 8 | + 0°1709 | 0.193049 | 41.907 | 26.90 | | 3 | 128549 | 0.134949 | 05.262 | 58.35 |
| | 8 | − 0°1890 | 0.212636 | 20.885 | 52.86 | | 3 | 128579 | 0.121630 | 06.027 | 54.85 |
| 1737 | 8 | + 4°1707 | 0.158666 | 12.754 | 58.65 | 1748 | 3 | 146955 | 0.140759 | 28.932 | 44.01 |
| AGK3 | 8 | + 4°1709 | 0.184847 | 29.453 | 21.97 | SAO | 3 | 146956 | 0.168810 | 32.949 | 40.97 |
| | 8 | + 3°1717 | 0.136313 | 48.137 | 12.58 | | 3 | 146991 | 0.185798 | 29.452 | 08.22 |
| | 8 | + 4°1717 | 0.200937 | 00.477 | 24.95 | | 3 | 147022 | 0.145162 | 33.164 | 38.50 |
| | 8 | + 3°1725 | 0.139159 | 17.470 | 16.13 | | 3 | 128551 | 0.196750 | 14.040 | 12.07 |
| | 8 | + 4°1721 | 0.180078 | 19.109 | 31.58 | | 3 | 128554 | 0.162722 | 37.073 | 13.47 |
| 1738 | 7 | + 5°1809 | 0.183721 | 26.568 | 44.46 | 1749 | 7 | +10° 522 | 0.171363 | 15.428 | 40.39 |
| AGK3 | 8 | + 4°1689 | 0.183338 | 53.942 | 35.25 | AGK3 | 7 | +11° 465 | 0.173203 | 36.765 | 59.52 |
| | 7 | + 6°1602 | 0.171547 | 53.166 | 47.19 | | 7 | +11° 470 | 0.170935 | 01.384 | 16.12 |
| | 8 | + 4°1696 | 0.159088 | 22.128 | 48.82 | | 7 | +10° 533 | 0.162934 | 53.611 | 16.72 |
| | 7 | + 6°1609 | 0.151645 | 20.414 | 48.35 | | 7 | +10° 541 | 0.159361 | 04.131 | 42.05 |
| | 7 | + 5°1820 | 0.150661 | 55.399 | 35.99 | | 7 | +11° 479 | 0.162205 | 22.343 | 45.03 |

TABLE 2 (Cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

| No. | Vol. | Star | Depend. | R.A. | Dec. | No. | Vol. | Star | Depend. | R.A. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1750 | 7 | + 7° 514 | 0.213504 | 10.659 | 29.90 | 1753 | 3 | 130130 | 0.214899 | 46.380 | 33.67 |
| AGK3 | 7 | + 6° 496 | 0.182020 | 31.650 | 09.20 | SAO | 3 | 130142 | 0.225507 | 31.215 | 56.32 |
| | 7 | + 8° 505 | 0.206288 | 21.879 | 07.78 | | 3 | 130143 | 0.145904 | 45.936 | 03.60 |
| | 7 | + 6° 502 | 0.134747 | 04.748 | 28.16 | | 3 | 130198 | 0.116247 | 59.401 | 51.52 |
| | 7 | + 6° 505 | 0.115738 | 20.749 | 51.04 | | 3 | 130200 | 0.172073 | 07.900 | 15.13 |
| | 7 | + 7° 534 | 0.147703 | 28.017 | 07.37 | | 3 | 130224 | 0.125370 | 03.454 | 45.10 |
| 1751 | 7 | + 5° 474 | 0.111996 | 15.069 | 56.82 | 1754 | 3 | 129931 | 0.184435 | 15.913 | 32.42 |
| AGK3 | 7 | + 6° 470 | 0.170023 | 50.858 | 17.05 | SAO | 3 | 129935 | 0.151352 | 02.317 | 14.94 |
| | 8 | + 4° 466 | 0.121279 | 06.436 | 26.90 | | 3 | 129937 | 0.194015 | 18.826 | 16.32 |
| | 7 | + 6° 477 | 0.213578 | 04.807 | 42.89 | | 3 | 129972 | 0.138693 | 42.684 | 33.75 |
| | 7 | + 5° 491 | 0.161290 | 06.639 | 38.22 | | 3 | 129988 | 0.150055 | 35.590 | 13.03 |
| | 7 | + 6° 490 | 0.221834 | 08.417 | 58.42 | | 3 | 129990 | 0.181451 | 45.708 | 04.29 |
| 1752 | 7 | + 5° 454 | 0.167572 | 58.613 | 18.77 | 1755 | 3 | 129708 | 0.174638 | 23.860 | 59.89 |
| AGK3 | 8 | + 4° 448 | 0.152134 | 23.988 | 53.38 | SAO | 3 | 129729 | 0.146800 | 54.312 | 09.01 |
| | 7 | + 5° 459 | 0.180683 | 30.337 | 45.74 | | 3 | 129743 | 0.112279 | 11.623 | 08.72 |
| | 7 | + 5° 467 | 0.178964 | 28.622 | 32.43 | | 3 | 129763 | 0.211522 | 23.813 | 32.17 |
| | 8 | + 4° 454 | 0.150672 | 56.125 | 08.49 | | 3 | 129776 | 0.154525 | 26.104 | 58.35 |
| | 7 | + 5° 469 | 0.169976 | 02.736 | 16.91 | | 3 | 129791 | 0.200236 | 39.705 | 57.31 |

TABLE 3

STANDARD ERRORS

| | | R.A. | Dec. |
|---|---|---|---|
| AGK3 | 4 image | $0^{s}.011$ sec $\delta$ | $0''.19$ |
| AGK3 | 2 image | $0^{s}.012$ sec $\delta$ | $0''.22$ |
| SAO | 4 image | $0^{s}.022$ sec $\delta$ | $0''.35$ |
| SAO | 2 image | $0^{s}.023$ sec $\delta$ | $0''.36$ |

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# A Preliminary Study of Polynuclear Aromatic Hydrocarbons in the Sydney Atmosphere

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ABSTRACT. Samples of suspended particulate matter collected over ten periods each of 24 hours during October, 1979, were segregated into five size fractions by a cascade impactor attached to the hi-vol sampler. These fractions have been analysed quantitatively for benzo[a]pyrene and qualitatively for 19 other polynuclear aromatic hydrocarbons. The results are compared with other published data for Melbourne and several cities in North America. Certain trends in the results are reported; namely the benzo[a]pyrene, as concentration in the atmosphere, is associated with the finest size fractions as is to be expected from other reports in the literature. However, when the results are expressed as concentration per unit mass of particulate matter, the highest concentration is in a larger size fraction, i.e. the 2.5 to 1.5 µm or 4.0 to 1.5 µm, (aerodynamic diameter) size. The concentration of benzo[a]-pyrene in the atmosphere increases as the concentration of suspended particulate matter decreases, and the number of other polynuclear aromatic hydrocarbons tend to increase as suspended particulate matter decreases. Another observation is that the benzo[a]pyrene concentration in the Sydney air-shed is the highest of that of the other cities reported, and is approached only by Hamilton, Ontario, which is an industrial city containing metallurgical industries. This result also appears to be supported by earlier-published data for Sydney. The analytical method, which involves thin layer chromatography (TLC) also is discussed.

## INTRODUCTION

It is well known that many polynuclear aromatic hydrocarbons (PAH) possess varying degrees of mutagenicity or carcinogenicity (Flessel et al., 1980). These compounds, which usually are formed by combustion processes (Badger, 1962) or by the degradation of automobile tyres (Cleary, 1968), are associated with the suspended particulate matter in the atmosphere. It has been shown that their concentrations in the gas phase are insignificant for practical purposes (Commins, 1962; Miguel and Friedlander, 1978) despite the comparatively high equilibrium vapour concentration (Pupp et al., 1974) possessed by some of them. Only with exceptionally long sampling periods - of the order of several weeks - are vapour losses of PAHs likely to be significant (König et al., 1980), although this view is not held by others (Katz and Chan, 1980; Lindgren et al., 1980).

Very little work has been undertaken on the concentrations of PAHs in the Sydney air basin apart from that of Cleary (1968) and Tseng (1975) in the early 1960's and mid 1970's respectively, and no work at all, as far as the authors are aware, on the concentration dependency on particle size. The most comprehensive report of work undertaken elsewhere (at the time of commencement of this investigation) is by Miguel and Friedlander (1978), who used a low pressure cascade impactor (Hering et al., 1978; Hering et al., 1979) to size segregate ambient Pasadena aerosols into 8 stages, ranging from 4.0 to 0.05 µm aerodynamic effective cut-off diameters (ECD), on each of which benzo[a]pyrene (BaP) and coronene (COR) were determined. Miguel and Friedlander (1978) ascertained that about 75% of the BaP and 85% of the COR are associated with particles of aerodynamic diameter less than 0.26 µm, and that almost half of the total mass of both PAHs is associated with aerosols in the narrow range of 0.075 to 0.12 µm. In reviewing earlier work on PAH concentrations in size-segregated aerosols, Miguel and Friedlander refer to six reports only, from which it may be concluded that a large percentage of the mass of the appropriate PAHs is associated with particles smaller than the smallest ECD of the collecting device used. (These reports describe samples from two sites in the USA, two in Canada, one in Budapest and one of a laboratory-produced smoke).

The present work was undertaken with two objectives in view. The first was to ascertain whether the PAHs in the Kensington locality of the Sydney air basin exhibit a preference for certain size fractions of the suspended particulate matter (SPM). The second was to evaluate the reliability of a rapid method of analysis, so that the large number of samples from multi-stage cascade impactors could be analysed conveniently by the minimum number of personnel in a laboratory equipped with average facilities.

## EXPERIMENTAL

### Aerosol Collection

The atmospheric suspended particulate matter (SPM) was collected by a high-volume sampler, situated approximately 50 m above ground on the roof of the Applied Science building at the University of New South Wales, Kensington. A four-stage cascade impactor with a 203 x 254 mm back-up filter was fitted to the filter holder of the high-volume sampler.

The flow rate of the sampler was determined by a previously calibrated orifice plate attached to the complete cascade impactor assembly, and was found to be 0.91 $m^3 min^{-1}$ when the ambient temperature was 24°C. The small monitoring rotameter at the fan outlet was calibrated accordingly, and the flow was found to be steady over the whole sampling campaign. This flow rate was used without further correction, as the prescribed adjusting formula for variations in ambient temperature and barometric pressure (Katz, 1977(i)) is:

$$Q_2 = Q_1 \left[\frac{T_2 P_1}{T_1 P_2}\right]^{\frac{1}{2}}$$

where $Q_2$ = corrected flow rate at temperature $T_2$ and pressure $P_2$

$Q_1$ = flow rate at calibration, when temperature and presssure were $T_1$ and $P_1$ respectively.

Application of this equation to the extremes of temperature listed in Table 2, and even allowing for a variation in atmospheric pressure of ± 3.37 kPa will lead to maximum variations of ± 0.03 of the mean flow rate value, which is negligible in the present context.

The 50% effective cut-off diameter (ECD) of the stages of the cascade impactor are 9.5, 4.0, 2.5 and 1.5 μm aerodynamic diameter, as provided by manufacturer's calibration. The glass fibre filter substrates and the back-up filter are weighed both before and after the taking of the samples. The filters are not conditioned at a constant relative humidity before the weighings (as recommended in the APHA Intersociety Committee procedure (Katz, 1977(i)), as a characteristic of the binderless glass fibre filters used is the absence of an adsorbed moisture correction over a wide range of ambient laboratory relative humidities. This has been verified by laboratory tests.

## Analysis of PAHs

### Survey of existing methods

Numerous methods (Katz, 1977(a)-(f); Katz, 1980) have appeared on this subject in recent years. Herod and James (1978) provide a detailed review of methods. The vast majority of the methods available fall into three stages, viz:

(a) extraction of the PAHs from the filter sample,

(b) separation of the individual species,

(c) identification and quantitative assessment of the separated compounds.

Concerning the first stage (a), most authors, including the many reviewed by Herod and James, use Soxhlet extraction of the filter with a variety of hydrocarbon solvents, of which benzene or cyclohexane predominate. This takes usually 4 to 8 hours; 24 hours is prescribed in Katz (1977(f)), but Mainwaring and McGuirk (1977) have shown that 97% of both benzene soluble matter and benzo[a]-pyrene (BaP) are extracted in the first four hours of a 22 hour period of Soxhlet extraction using benzene. Chatot et al. (1971), and more recently Bjorseth et al. (1980) and Flessel et al. (1980) have used ultrasonic extraction, and found this to be complete in 20 or 30 minutes.

The second stage (b) of the procedure invariably uses some form of chromatography, of which column chromatography (CC), high performance liquid chromatography (HPLC), gas chromatography (GC) and thin layer chromatography (TLC) are the principal examples. Gel permeation chromatography and mass spectrometry without prior separation by GC, also have received mention in references given. Of the chromatographic methods, CC invariably occupies 1 to 2 days, whereas the HPLC and TLC involve times in the general order of about 1 hour, and GC slightly less.

The third stage, (c), falls into two parts, namely identification of the compound on one hand and its quantitative assessment on the other hand. The identification usually is made by measurement of partition coefficient in TLC (frequently using a spot of pure BaP as a standard of reference), or by time of efflux in CC and GC. The position of the compound with reference to the solvent front in TLC is established by fluorescence under U.V. light of wavelength 366 nm, where in some circumstances the colour of the fluorescence on a wet or dry plate may give a secondary identification, as indicated in Table 1. A similar technique is used to identify the compounds on the HPLC column. In GC, the areas under the elution peaks (which are proportional to the amount of substance) are found either by the in-built integrators in the instrument or by manual integration of the read-out curves by planimeter. Types of detector reported as being used for PAH analysis are flame ionisation (FID), electron capture (ECD), mass spectrometry (MS), and ultra-violet (UV) (Katz, 1977(g),(h); Herod and James, 1979). For CC, the concentration of PAHs in the various chromatographic fractions is found by the base-line technique of Commins and Cooper (Katz, 1977(e)) from absorbance measurements at a specified wavelength in the ultra violet regime of the spectrum (UV). The evaluation of the amount of compound in the PAH zones on the TLC plates is undertaken either by UV absorption or UV fluorescence. This normally involves scraping off the coating (from the underlying glass plate) containing the zone of interest, dissolving the constituent in a suitable solvent, and after removing the dispersed phase of TLC coating material by filtration or centrifugation, the absorption of the remaining solution at appropriate wavelengths is measured in a UV spectrophotometer. A similar technqiue may be used for UV fluorescence, where the excitation and emission wavelengths are selected for each individual compound. However, the fluorescence of the spots directly on the TLC plates may be determined by a spectrofluorometer with attached TLC plate scanner (Miguel and Friedlander, 1978). The fluorescence method is more sensitive than the direct absorption method by a factor of about 100 (Miguel and Friedlander, 1978) but care must be exercised as it is known that quenching of the fluorescence by unknown impurities may occur.

The method adopted for this study

The initial extraction of the PAHs is accomplished by refluxing for 20 minutes the glass fibre substrate (or a known proportion of the back-up filter) with 15 mL of benzene in a 100 mL conical flask fitted with a "cold finger" reflux condenser. The flask is heated by being partially immersed in a beaker of water maintained at about 90°C. This is analogous to a method developed by Tseng (1975) who agitated the filter in gently boiling benzene for several minutes and thereby achieved an extraction in excess of 90% of the PAHs recoverable by a 6 hour Soxhlet extraction.

After refluxing, the contents of the 100 mL flask are filtered into a 25 mL conical flask, and the original flask and filter are washed several times with a total of about 3 mL of benzene. The 25 mL flask, now containing approximately 20 mL of benzene is gently evaporated almost to dryness at 40°C and reduced pressure of 5.3 kPa abs. The walls of the flask are washed with benzene from a micro-pipette, giving a final volume in the flask of about 100 μL. This is transferred as completely as possible by micro-pipette to the prepared chromatographic plate.

The 200 x 200 mm glass chromatographic plates are coated with a 250 μm layer of a slurry of 20 g of aluminium oxide G (type E) and 20 g of silica gel GF 254 (type 60) mixed with 66 mL of distilled water and applied with a suitable applicator. After drying, the plates are activated directly before use by being heated at 100°C for 10 minutes and then by cooling for a further 10 minutes in the laboratory atmosphere. The development tank (with insertion grooves to hold seven plates simultaneously) is prepared for use by introducing into it 200 mL of pentane:ether, 19:1 v/v, and allowing it to equilibrate for at least two hours.

The plates are spotted with a disposable micro-pipette 15 mm from the base. Each spot is accompanied in an adjacent position by another spot containing 0.22 μg of pure BaP to act as an identification standard. In addition to the five spots - with their accompanying standards - which result from each sample (i.e. 4 cascade impactor stages and the back-up filter), a sixth spot resulting from a calibration standard of a glass fibre substrate spiked with a known amount of pure BaP (0.1 to about 0.5 μg) is added as well.

The spotted plates are placed in the prepared TLC tank and are allowed to develop until the solvent front has reached a height of about 15 cm, which takes from 45 to 60 minutes. After development, the plates are examined under UV light of wavelength 366 nm and the fluorescent areas of the pure 0.22 μg BaP standard and the corresponding area of sample are marked with a sharp stylus. The position and colour of other fluorescent zones resulting from different members of the PAH family (see Table 1, from Sawicki et al., 1964) are also marked for subsequent identification. The marked areas of the plates containing the fluorescent zones of both the sample BaP and the 0.22 μg standard are scraped off the plate and transferred to centrifuge tubes for subsequent elution and analysis.

The BaP is eluted from the scrapings by adding 2 mL of dichloromethane to each centrifuge tube, then agitating for about five minutes and then centrifuging down the solid phase for a further two minutes. The superincumbent liquid is decanted into a 1 cm path length x 4 mL capacity spectrophotometer cell. The washing and centrifuging is repeated with smaller amounts of dichloromethane and the final volume in the spectrophotometer cell is accurately adjusted to 3.5 mL with dichloromethane. The absorbances are measured at the wavelengths of three experimentally determined prominent peaks for BaP, namely 389, 368 and 350 nm.

These wavelengths disagree with others quoted in the literature. For example Commins (1958) and Stanley et al. (1967) nominate 390, 382 and 375 nm for BaP in pentane, and Katz (1977(b)) quotes the same wavelengths for BaP in ether. However, an illustration in Katz (1977(b)) depicting absorbance vs wavelength for BaP in pentane shows peaks at 383, 376 and 360 nm, with a somewhat smaller peak at 345 nm, but no peak at all in the vicinity of 390 nm. Tseng (1975) found that the absorbance peaks for BaP in dichloromethane occurred at 390, 380 and 370 nm.

During the course of the analysis, exposure to light is kept to a minimum to prevent photodissociation of the PAHs. All operations which cannot be conducted in complete darkness (such as the development of the TLC plates) are carried out in subdued artificial light and exposure of the developed chromatograms to ultraviolet light in order to identify the spots, also is kept to a minimum.

RESULTS AND DISCUSSION

The meteorological and atmospheric pollution conditions which prevailed in Sydney (about 5 km north west of the sampling site in Kensington), as obtained from the State Pollution Control Commission and the Bureau of Meteorology, are shown in Table 2. The results of the BaP determinations from the samples obtained over the 24 hour periods (approximately 9.00 am to 9.00 am) on the corresponding days are shown in Table 3.

Although these results are insufficient to allow any lasting conclusions to be obtained, nevertheless certain trends are apparent. The first trend appears to be that when the SPM concentration in the atmosphere is high, the BaP concentration is low, and vice versa. Another is that in common with the results of other workers, the major proportion of the BaP is associated with the finest size fraction when recorded as ng/m$^3$ or as a percentage of the total BaP. However, it is apparent that the actual concentration of BaP in the particulate matter itself is highest in the 1.5 - 2.5 μm size fraction, and/or the next larger fraction, i.e. 2.5 - 4.0 μm. In sample No. 8 in Table 3 for October 24 - 25 1979, the Bap content of the particulate matter rises to a high value of 1730 μg/g (0.173%) in the 1.5 - 2.5 μm size fraction. This, of course, may be an anomalous result arising from a variety of possible but very unlikely causes, and it is a disadvantage of the

procedure that insufficient particulate matter is available (except on the back-up filter) to allow duplicate analyses. However, further work should establish the validity or otherwise of such results. Nevertheless the trend to high concentrations in this size fraction is evident in all of the results obtained in this preliminary study.

Table 4 lists BaP determinations for the atmospheres of Sydney and other cities, as obtained from the literature sources provided. From this limited amount of information, it may be observed that the BaP content of the Sydney atmosphere is high when compared with that of the other cities reported in this short list. In fact, it would appear that for the periods in question, Sydney is analogous to Hamilton, Ontario, which is an industrial city containing a large concentration of iron and steel manufacturing facilities. It is interesting to note that in the results presented by Katz and Chan (1980) (from which the Hamilton, Ontario, data for Table 4 has been abstrated) the most plentiful of the eight PAHs that these authors quantitatively determine is benzo[ghi]-perylene (BghiP), where figures from a low of 1.62 to a high of 19.32 $ng/m^3$ appear in their tables of results, and with annual averages of 15.19 and 10.55 $\mu g/m^3$ being quoted. In the same work (Katz and Chan, 1980) the next most plentiful compound is BaP, and this is followed by BeP (benzo[e]-pyrene.

In this present work, BaP was present in measurable quantity in all but four of the 50 chromatograms, but nevertheless was visible as a fluorescent spot on the remaining four. This compound was readily identifiable by its blue or purple fluorescence even without the adjacent presence of the 0.22 µg standard, and appeared in all instances to be the most plentiful constituent. However, BghiP, which appears as No. 13 in Table 5, certainly is not a major constituent of the Sydney PAHs as it is in Hamilton, Ontario.

Table 5, to which reference was made above, is self explanatory, and lists other compounds from the PAH group which have been identified qualitatively by their RF values and fluorescence colour. Another trend which may be observed from Table 5 is that as the particle size fraction decreases, so the number of PAHs increases. The largest number of PAHs are associated with stages 4 and 5 of the samples, although there are numerous unidentified fluorescent spots on all stages. (These have not been included in Table 5.) A prominent fluorescent green-blue spot appeared on many of the chromatograms at an RF value of 0.25, but this has not been identified.

CONCLUSIONS

Although this work has been introductory and exploratory in nature, and the analytical method is to be subjected to several modifications when the study is resumed, sufficient results have emerged to show that an interesting situation with regard to PAHs occurs in the Sydney air-shed.

If during the current decade, as appears likely, residents of the Sydney basin follow the example of many North American communities of returning to wood-burning open fires or slow-combustion stoves for domestic space heating, this will introduce another rich source of PAHs into the atmosphere. (See, for example, Cooper, 1980; Hall and DeAngelis, 1980; Budiansky, 1980). Consequently, it is intended to continue this work as time and circumstances permit, to accumulate data on PAH compounds and their prevalence, and endeavour to correlate these with meteorological, natural (e.g. bush fires) and anthropogenic activities. For this purpose, other cascade impactors, probably "commercial" but certainly "home made" (Hering et al., 1978; Hering et al., 1979; Marple and Willeke, 1976) with ECD's down into the sub-micrometre size range, will be employed.

The modifications which are being introduced into the analytical procedure (while retaining TLC as the basic method) is to adopt ultrasonic extraction of the original sample, the N,N-dimethylformamide-toluene extraction of the PAHs from the filtrate of the ultrasonic extraction operation described by Flessel et al. (1980), and to improve the reliability of the re-solution of the dry PAHs into 100 µL or so of a suitable solvent prior to spotting the TLC plates. Two dimensional or double development of the TLC plates as described by Mainwaring and McGuirk (1977) and Katz and Chan (1980) may be used to obtain better segregation of compounds. It is hoped that the suitability of a spectrofluorometer with a TLC plate scanner can be assessed for the final quantitative measurements.

TABLE 1
THIN-LAYER CHROMATOGRAPHIC SEPARATION OF PAH ON ALUMINIUM OXIDE USING PENTANE-ETHER (19:1, v/v) AS THE SOLVENT (Sawicki et al., 1964)

| Compound | RF Value* | Fluorescent Wet | Colour Dry | Ref. No. Table 5 |
|---|---|---|---|---|
| Pyrene | 1.25 | Blue | Blue | 1 |
| Anthracene | 1.14 | Blue | Blue | 2 |
| Phenanthrene | 1.13 | Light blue | Light blue | 3 |
| Chrysene | 1.10 | Blue | Pink | 4 |
| Fluoranthene | 1.09 | Blue | Light blue | 5 |
| 11H-Benzo(b)fluorene | 1.08 | Light blue | Light blue | 6 |
| Triphenylene | 1.07 | Light blue | Light blue | 7 |
| Benzo(e)pyrene | 1.04 | Green/blue | Green/blue | 8 |
| Benzo(a)anthracene | 1.03 | Blue | Pink | 9 |
| Benzo(a)pyrene | 1.00 | Blue | Pink | 10 |
| Benzo(k)fluoranthene | 0.98 | Blue | Blue | 11 |
| Perylene | 0.91 | Blue | Light yellow | 12 |
| Benzo(ghi)perylene | 0.89 | Blue | Yellow/green | 13 |
| Dibenzo(a,e)pyrene | 0.78 | Blue | Light yellow | 14 |
| Dibenz(a,h)anthracene | 0.74 | Blue | Blue | 15 |
| Anthanthrene | 0.71 | Blue | Light blue | 16 |
| Benzo(rst)pentaphene | 0.68 | Blue | Pink | 17 |
| Coronene | 0.46 | Green | Green | 18 |
| Dibenzo(h,rst)pentaphene | 0.12 | Green/blue | Light yellow | 19 |
| Benzo(a)coronene | 0.10 | Green/blue | Light yellow | 20 |

*RF Value is the distance travelled by the unknown PAH divided by the distance travelled by BaP.

TABLE 2
METEOROLOGICAL AND POLLUTION DATA FROM THE STATE POLLUTION CONTROL COMMISSION AND BUREAU OF METEOROLOGY

| Run | Date | Temp.(a) °C | Wind km/hr | Cloud | SPM(b) | SPI(c) |
|---|---|---|---|---|---|---|
| 1 | 10-11 | 32.7 | 40 | few | 76 | 62 |
| 2 | 11-12 | 18.7 | 20 | few | 28 | 26 |
| 3 | 15-16 | 20.3 | calm | scattered | 45 | 36 |
| 4 | 17-18 | 15.0 | calm | few | 17 | 30 |
| 5 | 18-19 | 19.6 | calm | hazy | 50 | 55 |
| 6 | 22-23 | 23.1 | 10 | hazy | 33 | 31 |
| 7 | 23-24 | 24.7 | calm | overcast | 42 | 49 |
| 8 | 24-25 | 20.5 | 20 | clear | 14 | 35 |
| 9 | 29-30 | 19.1 | 20 | clear | 17 | 28 |
| 10 | 30-31 | 19.8 | 20 | scattered | 9 | 44 |

(a) maximum recorded temperature
(b) SPM: suspended particulate matter, $\mu g/m^3$. Reading taken near Broadway, Sydney, between 8 a.m. and 4 p.m.
(c) SPI: Sydney pollution index, is given by the following formula:

$$SPI = 10\sqrt{(COH)^2 + \left(\frac{O_3 \text{ in pphm}}{4}\right)^2}$$

where COH = coefficient of haze per 1,000 linear feet

There are three arbitrary categories of SPI derived from statistical data:

| | |
|---|---|
| light | < 30 |
| medium | 30 - 45 |
| high | > 45 |

TABLE 3
SUSPENDED PARTICULATE MATTER IN SIZE SEGREGATED CATEGORIES, WITH CORRESPONDING BaP CONCENTRATIONS

| Aerodynamic diameter μm | SPM μg/m³ | SPM % | BaP ng/m³ | BaP % | BaP μg/g |
|---|---|---|---|---|---|
| No. 1, October 10-11, 1979 | | | | | |
| > 9.5 | 1.61 | 2.8 | - | - | - |
| 4.0 - 9.5 | 2.99 | 5.2 | 0.115 | 11.6 | 39 |
| 2.5 - 4.0 | 2.61 | 4.6 | 0.274 | 27.8 | 105 |
| 1.5 - 2.5 | 2.45 | 4.3 | - | - | - |
| < 1.5 | 47.36 | 83.1 | 0.599 | 60.6 | 13 |
| Total | 57.02 | 100.0 | 0.988 | 100.0 | |
| Average | | | | | 17 |
| No. 2, October 11-12, 1979 | | | | | |
| > 9.5 | 3.91 | 9.6 | 3.463 | 57.2 | 888 |
| 4.0 - 9.5 | 2.84 | 6.9 | 0.497 | 8.2 | 176 |
| 2.5 - 4.0 | 0.92 | 2.2 | 0.453 | 7.5 | 493 |
| 1.5 - 2.5 | 0.54 | 1.3 | 0.401 | 6.6 | 750 |
| < 1.5 | 32.87 | 80.0 | 1.241 | 20.5 | 38 |
| Total | 41.08 | 100.0 | 6.055 | 100.0 | |
| Average | | | | | 148 |
| No. 3, October 15-16, 1979 | | | | | |
| > 9.5 | 6.74 | 12.6 | 0.741 | 11.0 | 110 |
| 4.0 - 9.5 | 6.13 | 11.4 | 0.726 | 10.8 | 119 |
| 2.5 - 4.0 | 3.68 | 6.9 | 0.677 | 10.0 | 184 |
| 1.5 - 2.5 | 1.76 | 3.3 | 0.457 | 6.8 | 259 |
| < 1.5 | 35.33 | 65.8 | 4.139 | 61.4 | 117 |
| Total | 53.64 | 100.0 | 6.740 | 100.0 | |
| Average | | | | | 126 |
| No. 4, October 17-18, 1979 | | | | | |
| > 9.5 | 7.13 | 12.6 | 0.112 | 3.5 | 16 |
| 4.0 - 9.5 | 7.36 | 13.0 | 0.407 | 12.9 | 57 |
| 2.5 - 4.0 | 5.13 | 9.1 | 0.150 | 4.7 | 30 |
| 1.5 - 2.5 | 3.22 | 5.7 | 0.444 | 14.1 | 143 |
| < 1.5 | 33.72 | 59.6 | 2.046 | 64.8 | 63 |
| Total | 56.56 | 100.0 | 3.159 | 100.0 | |
| Average | | | | | 58 |
| No. 5, October 18-19, 1979 | | | | | |
| > 9.5 | 8.89 | 15.2 | 0.791 | 18.0 | 90 |
| 4.0 - 9.5 | 8.66 | 14.8 | 1.035 | 23.6 | 120 |
| 2.5 - 4.0 | 4.06 | 6.9 | - | 0.0 | - |
| 1.5 - 2.5 | 2.38 | 4.1 | 0.238 | 5.4 | 101 |
| < 1.5 | 34.48 | 59.0 | 2.329 | 53.0 | 68 |
| Total | 58.47 | 100.0 | 4.393 | 100.0 | |
| Average | | | | | 76 |
| No. 6, October 22-23, 1979 | | | | | |
| > 9.5 | 9.50 | 21.2 | 0.066 | 1.1 | 7 |
| 4.0 - 9.5 | 7.66 | 17.1 | 1.178 | 19.5 | 154 |
| 2.5 - 4.0 | 3.75 | 8.4 | 0.514 | 8.5 | 137 |
| 1.5 - 2.5 | 1.15 | 2.5 | 0.099 | 1.6 | 86 |
| < 1.5 | 22.76 | 50.8 | 4.173 | 69.3 | 183 |
| Total | 44.82 | 100.0 | 6.030 | 100.0 | |
| Average | | | | | 135 |
| No. 7, October 23-24, 1979 | | | | | |
| > 9.5 | 4.60 | 6.3 | 0.437 | 6.5 | 95 |
| 4.0 - 9.5 | 5.29 | 7.3 | 0.071 | 1.1 | 14 |
| 2.5 - 4.0 | 3.45 | 4.7 | 0.116 | 1.6 | 34 |
| 1.5 - 2.5 | 1.30 | 1.8 | 0.460 | 6.9 | 353 |
| < 1.5 | 58.31 | 79.9 | 5.631 | 83.9 | 97 |
| Total | 72.95 | 100.0 | 6.715 | 100.0 | |

(Cont'd)

TABLE 3 (Cont'd)

| Aerodynamic diameter µm | SPM µg/m$^3$ | SPM % | BaP ng/m$^3$ | BaP % | BaP µg/g |
|---|---|---|---|---|---|
| Average | | | | | 92 |
| No. 8, October 24-25, 1979 | | | | | |
| > 9.5 | 5.98 | 18.1 | 0.331 | 4.2 | 55 |
| 4.0 - 9.5 | 3.75 | 11.4 | 0.155 | 1.9 | 41 |
| 2.5 - 4.0 | 1.61 | 4.9 | - | 0.0 | - |
| 1.5 - 2.5 | 0.92 | 2.8 | 1.588 | 19.8 | 1730 |
| < 1.5 | 20.69 | 62.8 | 5.941 | 74.1 | 288 |
| Total | 32.95 | 100.0 | 8.015 | 100.0 | |
| Average | | | | | 244 |
| No. 9, October 29-30, 1979 | | | | | |
| > 9.5 | 7.05 | 23.1 | 1.284 | 53.7 | 182 |
| 4.0 - 9.5 | 3.22 | 10.5 | 0.049 | 2.1 | 15 |
| 2.5 - 4.0 | 1.92 | 6.3 | 0.116 | 4.9 | 60 |
| 1.5 - 2.5 | 0.84 | 2.7 | 0.507 | 21.2 | 602 |
| < 1.5 | 17.55 | 57.4 | 0.433 | 18.1 | 25 |
| Total | 30.58 | 100.0 | 2.389 | 100.0 | |
| Average | | | | | 78 |
| No. 10, October 30-31, 1979 | | | | | |
| > 9.5 | 9.04 | 26.9 | 0.136 | 3.7 | 15 |
| 4.0 - 9.5 | 6.67 | 19.9 | 0.021 | 0.6 | 3 |
| 2.5 - 4.0 | 2.84 | 8.4 | 2.499 | 68.0 | 881 |
| 1.5 - 2.5 | 1.15 | 3.4 | 0.082 | 2.2 | 71 |
| < 1.5 | 13.87 | 41.3 | 0.935 | 25.5 | 67 |
| Total | 33.57 | 100.0 | 3.673 | 100.0 | |
| Average | | | | | 109 |

TABLE 4
CONCENTRATION OF BENZO(a)PYRENE IN SYDNEY COMPARED WITH RESULTS FROM OTHER CITIES

| Location and period | SPM g/m$^3$ Average | SPM g/m$^3$ Range | BaP ng/m$^3$ Average | BaP ng/m$^3$ Range |
|---|---|---|---|---|
| Sydney | | | | |
| 1962 (1) | - | - | 4.5 | 2.5 - 6.3 |
| July 1964 (1) | 178 | - | 7.65 | - |
| July 1975 (2) | 60 | - | 1.8 | - |
| Oct. 1979 (this work) | 48.2 | 30.6 - 73.0 | 4.8 | 1.0 - 8.0 |
| Melbourne | | | | |
| Dec. 1974 (3) | 75.5 | - | 0.29 | 0.08- 0.65 |
| Pasadena | | | | |
| Dec. 1976 (4) | - | - | 1.06 | - |
| Toronto | | | | |
| Feb. 1974 (5) | 78.8 | 56.0-101.6 | 0.72 | - |
| Los Angeles | | | | |
| Jan. 1966 (6) | - | - | 2.2 | - |
| June 1972 (7) | 215 | - | 1.1 | - |
| 1974-75 (8) | - | - | 0.46 | - |

(Cont'd)

TABLE 4 (Cont'd)

| | | | | |
|---|---|---|---|---|
| Hamilton, Ontario | | | | |
| June 77 - May 78 (8) | | | | |
| (4 x 3 mth. Site (a) | 88.3 | 58.6-121.0 | 3.62 | - |
| averages) Site (b) | 103.1 | 93.6-120.0 | 3.65 | 2.5 - 4.7 |
| Jan. - May 78 (8) | | | | |
| Site (a) Cascade Impactor | - | - | 2.83 | - |
| Site (a) Hi-Vol. | - | - | 2.86 | - |
| Site (b) Cascade Impactor | - | - | 6.61 | - |
| Site (b) Hi-Vol. | - | - | 3.01 | - |
| Hamilton, Ontario | | | | |
| 1975 - 76 Site (a) (8) | - | - | 2.30 | - |
| New York City | | | | |
| 1975 (8) | - | - | - | 1.15- 1.30 |

References: (1) Hoffman (1968); (2) Tseng (1975); (3) Mainwaring and McGuirk (1977); (4) Miguel and Friedlander (1978); (5) Pierce and Katz (1975); (6) Stanley et al. (1968); (7) Gordon and Bryan (1973); (8) Katz and Chan (1980).

TABLE 5
TENTATIVE IDENTIFICATION OF OTHER PAHs ON THE TLC PLATES
FOR EACH STAGE OF EACH RUN

| Aerodynamic diameter μm | PAHs identified (Numbers identify the compounds in Table 1) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. 1 October 10-11, 1979 | | | | | | | | | |
| > 9.5 | 10 | 18 | 20 | | | | | | |
| 4.0 - 9.5 | 10 | 12 | 17 | 18 | 19 | | | | |
| 2.5 - 4.0 | 3 | 4 | 7 | 10 | 12 | 19 | | | |
| 1.5 - 2.5 | 7 | 8 | 10 | 13 | 17 | 19 | | | |
| < 1.5 | 6 | 10 | 12 | 14 | 16 | 17 | 19 | | |
| No. 2 October 11-12, 1979 | | | | | | | | | |
| > 9.5 | 4 | 10 | 14 | 19 | | | | | |
| 4.0 - 9.5 | 4 | 10 | 14 | 19 | | | | | |
| 2.5 - 4.0 | 4 | 6 | 10 | 14 | | | | | |
| 1.5 - 2.5 | 3 | 4 | 6 | 10 | | | | | |
| < 1.5 | 3 | 4 | 6 | 10 | 12 | 14 | 19 | | |
| No. 4 October 17-18, 1979 | | | | | | | | | |
| > 9.5 | 10 | 13 | 18 | 20 | | | | | |
| 4.0 - 9.5 | 6 | 10 | 13 | 14 | 18 | 20 | | | |
| 2.5 - 4.0 | 4 | 6 | 10 | 12 | 13 | 16 | 18 | 20 | |
| 1.5 - 2.5 | 10 | 12 | 13 | 14 | 16 | 18 | 20 | | |
| < 2.5 | 6 | 10 | 12 | 13 | 14 | 16 | 18 | 19 | 20 |
| No. 5 October 18-19, 1979 | | | | | | | | | |
| > 9.5 | 8 | 10 | 12 | 20 | | | | | |
| 4.0 - 9.5 | 10 | | | | | | | | |
| 2.5 - 4.0 | 8 | 10 | 12 | 18 | 20 | | | | |
| 1.5 - 2.5 | 10 | 20 | | | | | | | |
| < 2.5 | 10 | 12 | 18 | 20 | | | | | |
| No. 6 October 22-23, 1979 | | | | | | | | | |
| > 9.5 | 10 | 12 | 14 | | | | | | |
| 4.0 - 9.5 | 10 | 12 | 13 | 14 | 18 | 20 | | | |
| 2.5 - 4.0 | 8 | 10 | 12 | 14 | 16 | | | | |
| 1.5 - 2.5 | 7 | 10 | 13 | 14 | 18 | 20 | | | |
| < 1.5 | 8 | 10 | 12 | 20 | | | | | |
| No. 7 October 23-24, 1979 | | | | | | | | | |
| > 9.5 | 10 | | | | | | | | |

(Cont'd)

TABLE 5 (Cont'd)

| Aerodynamic diameter μm | PAHs identified | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4.0 - 9.5 | 7 | 8 | 10 | 13 | 14 | 15 | 19 | 20 |
| 2.5 - 4.0 | 7 | 8 | 10 | 11 | 12 | 14 | 19 | 20 |
| 1.5 - 2.5 | 4 | 7 | 8 | 10 | 14 | 16 | 19 | 20 |
| < 1.5 | 7 | 8 | 10 | 13 | 20 | | | |
| No. 8 October 24-25, 1979 | | | | | | | | |
| > 9.5 | 4 | 10 | | | | | | |
| 4.0 - 9.5 | 4 | 10 | 12 | | | | | |
| 2.5 - 4.0 | 4 | 10 | | | | | | |
| 1.5 - 2.5 | 4 | 10 | 12 | | | | | |
| < 2.5 | 4 | 10 | 12 | | | | | |
| No. 9 October 29-30, 1979 | | | | | | | | |
| > 9.5 | 4 | 8 | 10 | 12 | | | | |
| 4.0 - 9.5 | 4 | 8 | 10 | 12 | 14 | 16 | 19 | 20 |
| 2.5 - 4.0 | 4 | 8 | 10 | 12 | 13 | 19 | 20 | |
| 1.5 - 2.5 | 8 | 10 | 12 | 13 | 14 | 19 | 20 | |
| < 1.5 | 4 | 8 | 10 | 12 | 13 | 19 | 20 | |
| No. 10 October 30-31, 1979 | | | | | | | | |
| > 9.5 | 2 | 5 | 10 | 20 | | | | |
| 4.0 - 9.5 | 5 | 10 | 16 | 20 | | | | |
| 2.5 - 4.0 | 5 | 10 | 14 | 20 | | | | |
| 1.5 - 2.5 | 5 | 10 | 13 | 20 | | | | |
| < 1.5 | 5 | 10 | 13 | 14 | 19 | 20 | | |

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# Deformational History of the Coffs Harbour Block

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ABSTRACT. Within the Coffs Harbour Block three Permian deformational episodes have been identified, two being expressed on the mesoscopic scale and the third being obvious only on the macroscopic scale. The first deformation, $D_1$, produced upright mesoscopic folds in bedding and an associated axial-surface cleavage. Structures of this phase clearly increase in intensity of deformation towards the south of the block, and are accompanied by an increase in the mineralogical grade of regional metamorphism. The second deformation, $D_2$, although widespread, was not as intense as the first but formed gentle flexures, kinks and chevron folds. The distribution of lithologic units and mesoscopic structures suggests that the Coffs Harbour Block as a whole is a complex macroscopic syncline which developed at a late stage after the $D_1$ and $D_2$ deformations.

## INTRODUCTION

The Coffs Harbour Block in northern New South Wales consists of a monotonous sequence of Late Palaeozoic greywacke, siltstone, laminated mudstone and massive argillite, the petrography of which has been described by Korsch (1978a). Two regional metamorphic events were recognised by Korsch (1978b), the first being a progressive low-grade event with metamorphic recrystallisation increasing southwards, and the second being a static thermal event. The present aim is to outline the geologic structures present and to provide a deformational history for the block.

Within the Coffs Harbour Block three "generations" of folds have been identified, two being expressed on the mesoscopic scale and the third being obvious only on the macroscopic scale. The two mesoscopic generations, $D_1$ and $D_2$, are recognised by means of overprinting relationships and by different orientations of their structural elements. Throughout most of the block a single mesoscopic deformation phase, $D_1$, has produced folds varying from open to almost isoclinal. An axial-surface cleavage is common, particularly in the pelitic rocks, and at some localities it has been folded during a second deformation. The second deformation phase, $D_2$, whilst widespread, appears to have been less intense than the first and the structures are less obvious.

For the purposes of this paper the Coffs Harbour Block is subdivided into the Redbank River Beds (Korsch, 1971) and the Coffs Harbour "sequence" which consists of the Moombil Beds, Brooklana Beds and Coramba Beds (Korsch, 1978c). The Redbank River Beds are predominantly cherts and crop out only in the vicinity of Red Rock (Fig. 1). They are lithologically distinct from the remainder of the rocks in the Coffs Harbour Block and Korsch (1973) has shown that they are also structurally distinct. Two styles of folds related to two separate deformations have been recognised, but neither can be correlated with the two episodes of mesoscopic deformation described below from the Coffs Harbour sequence.

TABLE 1
STRUCTURAL ELEMENTS FOUND IN THE COFFS HARBOUR BLOCK

Planar Elements

Primary layering (bedding), $S_0$

Axial-surface cleavage, $S_1$

Axial surfaces of folds associated with $S_1$

Axial surfaces of $D_2$ kink bands and gentle warps, $S_2$

Linear Elements

Fold axes of $D_1$ mesoscopic folds, $B^{S_1}_{S_0}$

Intersection of $S_0$ and $S_1$, $L(S_0 \times S_1)$

Intersection of $S_0$ and $S_2$, $L(S_0 \times S_2)$

Intersection of $S_1$ and $S_2$, $L(S_1 \times S_2)$

Fold axes of $D_2$ mesoscopic folds $B^{S_2}_{S_0}$, $B^{S_2}_{S_1}$

## MESOSCOPIC STRUCTURES

Planar and linear elements recognised in the Coffs Harbour Block are listed in Table 1. Mesoscopic folds produced by $D_1$ are abundant throughout the Coffs Harbour Block but the best exposures are the coastal headlands between Broomes Head and Bonville Headland. These folds in $S_0$ change in shape and attitude in a systematic manner from north to south, with interlimb angles becoming smaller and plunges of the fold axes becoming steeper. The observed styles of $D_2$ folds both in $S_0$ and $S_1$ vary from slight flexures through kinks to tight chevron folds.

## MACROSCOPIC GEOMETRY

In a typical structural analysis it is customary to divide a region into homogeneous domains after having determined the orientation of the structural elements throughout the region. This method has been described in detail by Turner and Weiss (1963). In the Coffs Harbour region the

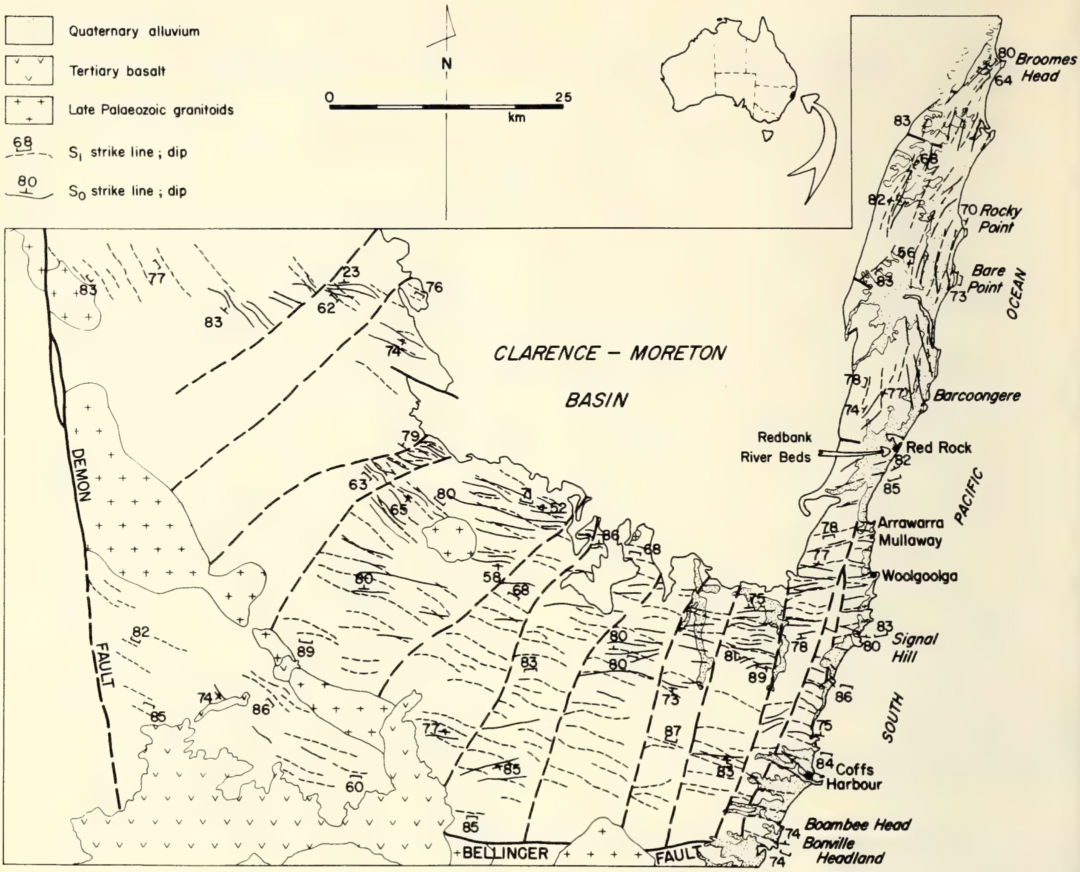


Fig. 1. Structural map of the Coffs Harbour Block showing the trends of $S_0$ and $S_1$. The Coffs Harbour sequence occupies the unpatterned area to the east of the Demon Fault, north of the Bellinger Fault and south and east of the Moreton Basin. Mapped faults are shown in solid lines and the positions of inferred faults are suggested by the broken lines.

usual methods of structural analysis cannot be applied rigorously because of the size of the region (over 4000 km$^2$), lack of access, poor exposure and considerable weathering. Hence this paper attempts to outline some of the features of the structural history of the whole region. The presence of macroscopic structures in the Coffs Harbour Block has been inferred largely from changes in the orientation of mesoscopic structures, and the distribution of lithologic units and metamorphic zones.

ORIENTATION AND DISTRIBUTION OF $D_1$ STRUCTURES

The most commonly observed mesoscopic structures in the Coffs Harbour Block are $S_0$ and $S_1$. For the inland exposures most of the data (except for $S_1$) have been collected in the northern part where $S_0$ is readily observable. $S_0$ is not observed as frequently as $S_1$ in the south. To simplify the discussion of the regional structure, the region has been divided into two subdivisions separated by the Redbank River Beds. To conserve space, the distribution of domains within the subdivisions and stereographic projections for the structural elements from each domain are not presented here but copies of the figures can be obtained from the author. Korsch (1973, Fig. 1a-1f) presented π-diagrams for some structural elements from the thin coastal strip around Woolgoolga.

Subdivision 1

This subdivision occupies the region from Red Rock south to the Bellinger Fault and west to the Demon Fault. Within it $S_1$ varies in strike from 137° in the northwest to 078° on the coast at Arrawarra, and indicates a general progressive change from west to east across the block. Dips of $S_1$ are very steep either to the north or to the south and can be in both directions within one outcrop.

$S_0$ exhibits orientations slightly different from that of $S_1$. Strikes range from 124° in the

northwest to 070° just inland from the coast near Arrawarra, and dips are very steep to both the north and south. This change in strike can also be observed in the coastal headlands from south to north. Except where localised mesoscopic folds occur, the bedding faces to the north. South-dipping beds from inland areas young to the north and are overturned. During $D_1$, $S_0$ was folded about horizontally to steeply-plunging axes trending approximately to the east or west. The fold axes are not entirely parallel but this might be due to the later effects of the $D_2$ deformation.

Subdivision 2

Most data from this subdivision, which occurs to the north of Red Rock and east of the Moreton Basin, have been collected from the well-exposed rocks of the coastal headlands. Average strikes of $S_1$ range from 000° to 049° and dips are always steep, usually greater than 70°, with dip directions to both the east and west.

Along the coastal strip between Red Rock and Rocky Point the average dip of bedding is steeply to the west (about 70° - 75°) whereas from north of Rocky Point to Broomes Head the average dip is steeply to the east (about 60° - 65°). All facing evidence indicates that the sequence faces to the west, and that beds which dip to the east are overturned. $S_0$ was folded about horizontal to steeply-plunging fold axes ($B^{S1}_{S0}$) trending either to the north or to the south. The fold axes are not entirely parallel as indicated by the variation in plunges of fold axes noted at various headlands. This may be due to the $D_2$ deformation.

Progressive change in intensity of $D_1$

In Subdivision 1 there is a progressive change from north to south in the plunge of the fold axes from subhorizontal to steeply-plunging and, associated with this, the interlimb angles of mesoscopic folds change from open to tight. In the north, parallel folds occur, but in the south the folds are flattened by a strain, $(\lambda_2/\lambda_1)^{\frac{1}{2}}$ of between 0.5 to 0.6 (determined using the technique of Ramsay, 1967, Fig. 7-79). The above features indicate a progressive increase in the intensity of the $D_1$ deformation towards the south.

The comments below refer more particularly to the well exposed coastal headlands, because of the paucity of significant data from the less well exposed inland outcrops.

*Subdivision 1*: The change in plunge of fold axes with increasing deformation might be explained by a model where an originally horizontal bed is being deformed and a near vertical axial surface is developing. Korsch (1979) has shown that it is possible to have a simple geometric relationship where the plunges of the fold axes change progressively while the dip of the axial surface remains constant. However, the limiting condition is that the strike of the marker horizon and the strike of the axial surface must not be the same. In Subdivision 1 the strikes of bedding and cleavage within domains are never the same, but differ by a few degrees (usually 6° - 24°) between average planes of $S_0$ and $S_1$. In general, in this subdivision a small interlimb angle correlates with a steep dip in bedding and a steep plunge in the fold axis. $D_1$ folds from Subdivision 1 are considered to have formed as the result of an axial load which was horizontal and directed from the south. Mechanisms such as the Coffs Harbour Block being buttressed by rocks from the Nambucca Slate Belt or the Coffs Harbour Block being forced against a stable Nambucca Slate Belt are considered possibilities.

*Subdivision 2*: A simple progressive change in one direction similar to that observed for fold axes and interlimb angles in Subdivision 1 does not occur. The relationship between interlimb angles and dips of bedding indicates that there is a much steeper dip for the bedding in this subdivision than that observed for similar interlimb angles in Subdivision 1. If there has been any rotation of this northern subdivision then the plunges and dips could have been less originally than their present amount. Hence the only variable which would not be affected by the rotation would be in the interlimb angle. Interlimb angles from this subdivision are similar to those from Arrawarra and Mullaway possibly suggesting that this subdivision was located to the east of Arrawarra prior to the proposed rotation.

It has not been possible to delineate any macroscopic structures in the Coffs Harbour Block produced by $D_1$ apart from the steepening in the orientation of the bedding. This is partly because of poor exposure but if any macroscopic fold developed it would have been refolded or displaced by subsequent folding and faulting during $D_2$ or $D_3$ deformations.

ORIENTATION AND DISTRIBUTION OF $D_2$ STRUCTURES

Mesoscopic structures produced by $D_2$ are gentle flexures, kink bands and chevron folds in $S_0$ and $S_1$, and occur throughout the Coffs Harbour sequence. In general, $D_2$ folds from Subdivision 1 have axial surfaces which are approximately north-south in strike. This contrasts with those from Subdivision 2 which have an east-west to northwest-southeast strike. $D_2$ structures are not as common as $D_1$ structures and it was not possible to define any macroscopic structure associated with this deformation.

WARPING OF BEDDING AND CLEAVAGE

Any explanation for the gentle warping of the bedding and cleavage throughout the block which produced slight changes in the orientation of the s-surfaces (Fig. 1) must also explain how the steeply-dipping beds often became overturned. The bedding has been deformed from an originally sub-parallel surface into one which dips steeply to the north or to the south, but youngs in one direction only, namely to the north. Hence while the possibility of isoclinal folding can be negated several other possibilities can be considered.

One possibility is that the monotonous sequence might have been deformed due to drag along the postulated faults shown on Fig. 1. Movement might result in slight twisting and drag of the sediments between two faults, particularly

if there has been any rotational component of movement along the faults. The beds could be deformed from an originally parallel sequence into one with dips which are steep in both directions but faces in one direction only.

Alternatively, the warping might be the result of a series of thrust faults with only small displacements. These thrusts would parallel the strike of the beds and hence they would be extremely difficult to locate. Only one such fault has been found, at Signal Hill (GR 6308 2616, Coffs Harbour 1:250 000) where a thick, massive greywacke unit has been thrust over a well-bedded sequence which has been slightly deformed by drag along the thrust. The patterns produced by this mechanism would explain slight changes in strike as well as changes in dip without a change in the facing direction, and may help explain the apparent enormous thickness of sediment in the Coffs Harbour sequence.

Another possibility is minor warping caused by gentle buckling during either $D_2$ or $D_3$ deformations. A further alternative is that regional-scale overturning of $S_0$ prior to $D_1$ could have occurred. This type of situation has been described around Rockvale to the west of the Coffs Harbour Block by Korsch (1975) and would result in both upright and inverted surfaces which were later modified by $D_1$.

Several of the above alternatives could have contributed to the warping and localised overturning, but the solution will not be resolved until detailed study of the structure of inland exposures has been completed.

### $D_3$ MACROSCOPIC STRUCTURE

The overall distribution of lithologic units suggest that the Coffs Harbour Block could be a large complex syncline. The older units (Moombil Beds and Brooklana Beds) are exposed on the western and southern periphery of the block and the younger Coramba Beds generally crop out closer to the Moreton Basin which may fill the hinge zone of the syncline. The development of the syncline is considered to be a late-stage event post-dating the mesoscopic features formed during $D_1$ and $D_2$. Evidence for the syncline is as follows:

(a) The headland of Red Rock is the critical area in the synclinal structure. Here, the well-bedded jaspers and cherts of the Redbank River Beds crop out. These rocks were not observed elsewhere in the Coffs Harbour Block and they separate what are considered the two limbs of the syncline occurring to the north and to the south. The two subdivisions outlined previously correlate with these two limbs.

(b) The strike of the bedding ranges from 124° to 070° and younging is to the north in sediments south of Red Rock, in contrast with strikes of 355° to 037° and younging to the west, in the north.

(c) The strike of the cleavage ranges from 137° to 078° south of Red Rock in contrast to strikes of 000° to 049° in the north.

(d) Differences in the orientation of the $B^{S_1}_{S_0}$ fold axes occur. In Subdivision 1 the fold axes vary from subhorizontal to steeply-plunging and trend either to the east or the west. This contrasts with Subdivision 2 where the fold axes are usually moderately plunging and trend either to the north or to the south. In Subdivision 2 the beds have suffered a rotation which steepened the beds relative to the equivalent rocks in Subdivision 1.

(e) The similarity of $D_1$ interlimb angles between Subdivision 2 and the headlands of Arrawarra and Mullaway suggest these districts were located possibly along strike from each other during the time of the first deformation.

(f) The orientations of the $D_2$ folds differ between subdivisions. The differences in the orientation could be due to either a subsequent folding after the $D_2$ deformation or to differences in attitude of the initial foliation prior to the deformation. The orientations of $D_2$ kinks for the two subdivisions suggest that rotation of the beds possibly occurred after the development of the $D_2$ mesoscopic structures, although this is not definitive evidence.

The above points suggest that orientations in Subdivision 1 are significantly different from those in Subdivision 2 and indicate the presence of a large macroscopic syncline. A series of faults dissecting the block and associated with the macroscopic syncline are postulated (Fig. 1). The fault surfaces are very rarely exposed and hence the dips are indeterminable. Criteria used to infer the faults include:

(a) Termination of lithologic units along their strike direction. This may be due to isoclinal folding, but no supporting evidence has been found. The three-fold subdivision of the Coffs Harbour sequence (Korsch, 1978c) and the four-fold petrographic subdivision of the Coramba beds (Korsch, 1978a) indicate, by their areal distribution, that no major repetition of lithologies by thrusting or isoclinal folding has occurred. Facing evidence indicates that the beds young consistently in one direction and the termination and displacement of particularly the units within the Coramba beds suggests a pattern of faulting.

(b) Differences in orientation of structures occur between adjacent areas separated by the faults. Within the area bounded by two faults the strikes of bedding and cleavage are consistent, but there is a difference usually of more than 5° from one fault bounded area to the next. Each fault bounded area constitutes a separate structural domain which was defined on the basis of orientation patterns of mesoscopic structures. In particular, fold axes are diagnostic, plunging towards the west in one block and plunging to the east in adjacent blocks.

(c) Discordances in metamorphic grade occur, as the metamorphic zones appear to have been displaced across the faults (Korsch, 1978b). The zones, which do not coincide with

stratigraphic units, are displaced so that in some places rocks from a lower grade are adjacent to those from a much higher grade.

(d) The presence of sheared and, less commonly, brecciated rocks suggest faulting of some form. For example a native mercury deposit located 5 km northwest of Woolgoolga (GR 6286 2710, Coffs Harbour 1:250 000) was found to lie in a shear zone striking almost due north, and is coincident with the position of one of the faults inferred here.

(e) The position of most of the inferred faults are coincident with linear features on aerial photographs.

The main component of movement on the faults was strike-slip. In some cases a horizontal component of 6 km is required to realign the lithologic boundaries. A slight vertical component may be present because thicknesses of the units differ across adjacent faults. It has not been possible to determine the amount of strike separations, but in most cases the movement was right lateral.

## CONCLUSIONS AND TECTONIC SPECULATIONS

Insufficient data are available to allow precise dating of the various episodes of deformation. Korsch (1973) concluded that the two mesoscopic deformational events observed in the Woolgoolga district were both phases of one major period of tectonism which occurred at the time of the Hunter-Bowen Orogeny. However, Harrington and Korsch (in press) showed that in the past two different and separate deformations have been confused, and combined under the term Hunter-Bowen Orogeny. Therefore up until now, in most parts of the New England orogen, almost all deformations have been correlated with the Hunter-Bowen Orogeny.

The concordant relationship of the Hillgrove-type Dundurrabin Granodiorite and its internal foliation with the regional orientation of the $D_1$ cleavage suggests that $D_1$ occurred at approximately the same time as the intrusion of the Hillgrove Plutonic Suite between 295 and 273 m.y. ago. This led Harrington and Korsch (in press) to suggest that the first deformation occurred in Permian Fauna III time, and that the second and third deformations might have occurred in Permian Fauna IV time or later.

There is a clear relationship between low-grade regional metamorphism and $D_1$ deformation in the Coffs Harbour Block. The cleavage in the Coffs Harbour Block exhibits an axial-surface relationship with $D_1$ mesoscopic folds. In places the cleavage is defined by the preferred orientation of metamorphic phases, particularly white mica and consequently there is a very close temporal relationship between low-grade regional metamorphism and the $D_1$ deformation. The metamorphism in the Coffs Harbour Block is part of a low-pressure belt which in turn is part of a pair of metamorphic belts in eastern New England (Korsch, 1978b). The medium-pressure belt lies south and west of the low-pressure belt. The metamorphic belts developed simultaneously with deformation which produced a clear and gradual deformational gradient from open, horizontal folds in the north to tight, steeply-plunging folds in the southern part of the Coffs Harbour Block. Hence $D_1$ deformation is considered to have occurred during a phase of convergent tectonism in the early Permian.

The $D_2$ deformation possibly resulted from movement on a plate boundary, located to the east of the present coastline, which produced the northerly trending mesoscopic folds and is interpreted by Harrington and Korsch (in press) as resulting from a major west-dipping subduction zone located near the present coastline. The subduction zone was also the cause of a major arc of granitoids and volcanics of which the New England Batholith *sensu stricto* is a part. The $D_2$ deformation in the Coffs Harbour Block is therefore correlated with the traditional Hunter-Bowen Orogeny.

The macroscopic $D_3$ syncline formed prior to the deposition of the Moreton Basin (McElroy, 1962), the earliest sediments of which are middle-Middle Triassic in age. No evidence has been found for the continuation of the associated inferred faults into the Mesozoic sediments and hence $D_3$ movement ceased prior to Middle Triassic time. The position of the $D_3$ macroscopic syncline defined the limits to the deposition of sediments in the southern part of the Moreton Basin as no extensive outliers of Moreton Basin sediments occur covering the Coffs Harbour sequence away from the basin proper. The rocks of Subdivision 2 and the northern part of Subdivision 1 probably acted as a barrier which confined the deposition of the Mesozoic sediments mainly to their present observable area.

The $D_3$ folding was probably completed prior to the emplacement of several granitoids, some of which have New England Batholith affinities and others have Stanthorpe Suite affinities. Hence it is considered likely that the $D_3$ deformation occurred during the late Permian at a slightly later time than the $D_2$ deformation.

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# Formation of "Beach Bubbles" on Quartz Sand Beaches of the Illawarra Coast, New South Wales

R. A. FACER

ABSTRACT. Gentle mounds or "beach bubbles" have been observed on several quartz sand beaches of the Illawarra district of New South Wales. These mounds or sand domes are generally 50mm to 150mm across and occur as intact (non-breached) crusts up to 20mm thick over a domed cavity as much as 10mm high. The sand of the "beach bubbles" is indistinguishable on the basis of sieve analysis data from the other surface sand of the beach. "Beach bubbles" develop near the top of the swash line on gently sloping beaches, but under a variety of tidal and wave conditions. Development apparently occurs by uplift of a crust of sand by air not being able to escape through the wet sand during and immediately following backwash. Preservation of these transient features — they generally collapse and re-establish in a different site after successive waves — would require very special conditions.

## INTRODUCTION

The Illawarra coast of New South Wales has many cuspate to zeta beaches which consist primarily of quartz sand. (Minor examples of boulder beaches are present.) This quartz sand is mainly derived from sandstones of the Permian-Triassic sequence of the southern Sydney Basin (Fig. 1) (cf. Langford-Smith and Thom, 1969). Processes influencing the present sediment supply are minor fluvial inflow (although coastal streams are generally quite small), supply from the continental shelf, and direct coastal erosion of the rocks.

Movement of sand on the beaches is predominantly wave action, resulting in on-offshore sediment transport. Minor longshore movement occurs with seasonal shifts in wave direction. If modal wave height is taken to be 1.5m, then waves below 1.5m height would lead to beach accretion and above 1.5m to beach erosion (Short, 1979). Wind action is also important, and in places there are extensive coastal dunes. In some beach sands local concentrations of shell fragments occur, but there is no present development of "beach rock".

Surface and near-surface structures on the sand beaches are generally typical of wind and wave action, plus invertebrate burrowing and rain prints. The beach profile typically consists of a shallow (3° to 5° slope) seaward-sloping swash zone (with occasional wave-cut scarps and berms) backed by a gentle slope of dry sand, and localized dune development on some beaches. However, minor features have been observed which are here termed "beach bubbles", although they are similar to "sand domes" of Emery (1945) and have some similarity to "mounds" described by Trefethen and Dow (1960).

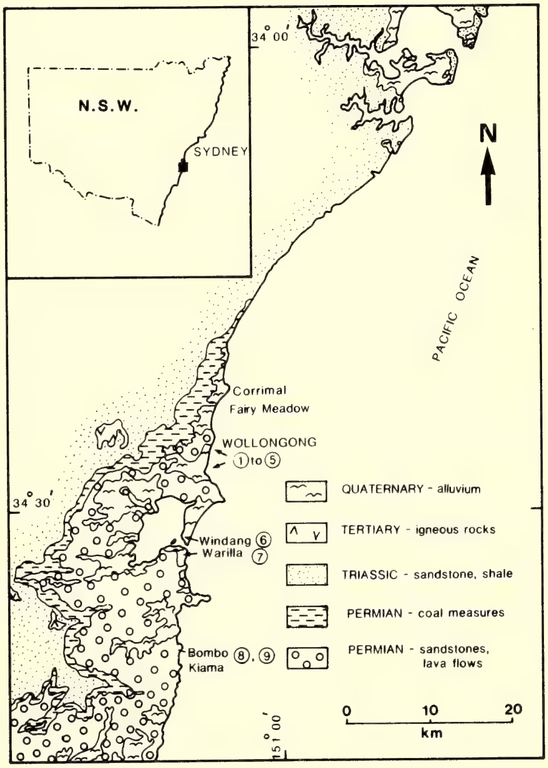


FIG. 1 Map showing locations of nine sites along Illawarra coast beaches from which "beach bubble" samples were collected. 1 to 5 were 50m, 150m, 170m, 300m and 400m from the N end of South Wollongong Beach, 6 was 100m N and 7 was 100m S of the entrance to Lake Illawarra (the coastal lagoon shown), and 8 and 9 were 40m and 100m from the N end of Bombo beach. The geology is simplified from that of Brunker and Rose (1969).

## FIELD DESCRIPTION OF "BEACH BUBBLES"

On a number of occasions (over 10 months), and on a number of beaches (including those shown on Figure 1), transient features have been observed at or just seaward of the swash line. These features appear as small circular to sub-circular

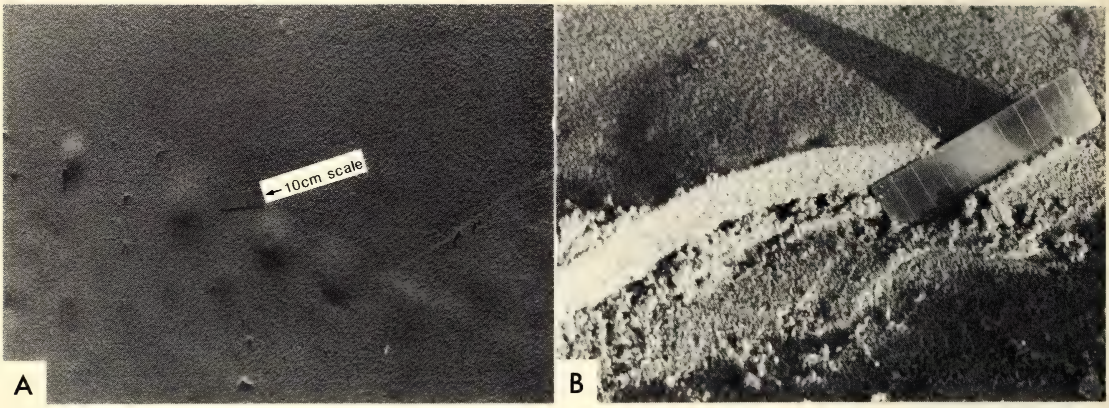


FIG. 2 Photographs illustrating "beach bubbles" on South Wollongong beach. The scale is 10cm long in each view. A) Swash froth line showing typical distribution of "beach bubbles". B) Dissected "beach bubble" showing internal cavity. The inner surfaces are apparently smooth, although dissection disturbs the sand to yield a layer of loosened sand.

swellings. The diameter of these "beach bubbles" was observed to be within the range 50mm to 150mm, and their height was as much as 10mm to 20mm above the otherwise flat sand surface (Fig. 2). In general, the cavity is a few millimetres to 10mm high, beneath a crust of slightly greater thickness — the crust and cavity dimensions being roughly proportional to the diameter of the "beach bubble". There is a domed top to the cavity and the floor is flat and parallel to bedding in the beach sediments.

The "beach bubbles" were apparently restricted to the sand at the top of the swash zone, often in a line just seaward of the topmost froth line (Fig. 2A), although solitary bubbles also occurred. When first studied they were observed to be concentrated between cusp horns on a low sloping (approximately 3° towards the ocean) beach below a minor wave cut scarp. Subsequently it was established that they occurred under various beach conditions: all tide stages; small to large waves on varying swells; gentle to strong (including gale force) onshore and offshore winds; with and without cusps, berm(s) or scarps; and even on a slight back berm slope. The "beach bubbles" invariably occurred above the static water table (this is discussed further, below). There remained a tendency for the "beach bubbles" to occur near or just below the swash line of the highest 5 per cent to 20 per cent of all waves. Although infiltration of the returning wave water occurred, the extent was variable. In an extreme case infiltration was 100% on the back-berm slope of Bombo beach.

Some "beach bubbles" were penetrated by worm burrows or holes, and some occurred in a small pebbly patch. Neither of these variations from the common state appeared to influence their development.

"Beach bubbles" have also been observed on One Mile beach, Forster (approximately 300km north of Sydney). It is not suggested here that these features are restricted.

THE SAND OF THE "BEACH BUBBLES"

The sand of the crusts of several "beach bubbles" was sampled, together with a bulk sample of the surface sand at the same site. This bulk sample was made up of three to five small, equal samples taken from surface sand from just below the swash line up the beach at 10m intervals across the whole beach. All samples were dried, split, and subjected to a routine sieve analysis (sieve interval $0.5\phi$). The results were plotted (Fig. 3) and various statistical parameters determined (cf. Folk, 1974, pp. 41-48).

Results of the graphic (Fig. 3) and statistical analyses (Table 1) indicate that there are few significant differences within the overall sample population. There are five pairs of "beach bubble" and bulk samples (1, 3, 5, 8 and 9). Comparison of these five pairs shows:

(i) in three pairs the sand of the "beach bubble" is slightly coarser than the bulk sample;

(ii) in three pairs the standard deviation is lower in the "beach bubble";

(iii) in three pairs the skewness is the same, with one "beach bubble" less symmetrical and one more symmetrical; and

(iv) the kurtosis relativities are variable.

As these differences tend to be slight there is no apparent graphical or statistical distinction of the "beach bubbles" from the remainder of the beach sands.

FORMATION OF "BEACH BUBBLES"

It has been possible to study the development of "beach bubbles" on Fairy Meadow beach during waves (breakers 25cm high on average, wavelength 8 to 10 metres) with very even swash run-up, just after low tide on a beach of 4° to 6° (variable)

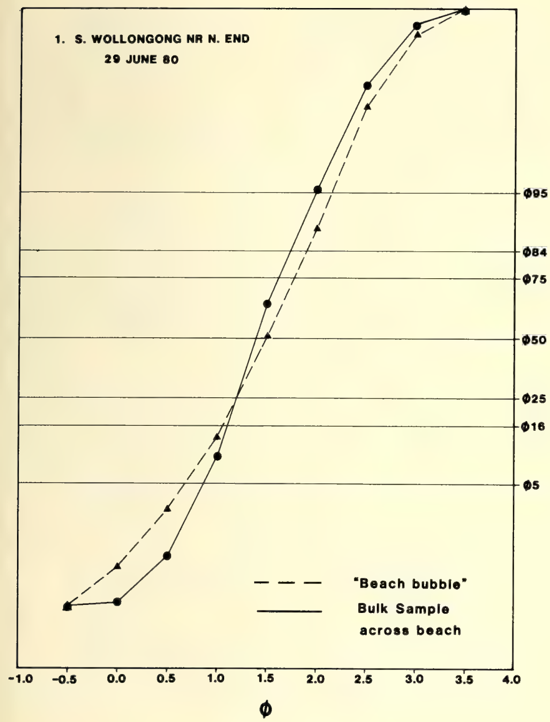


FIG. 3 An example of a cumulative plot of sieved sand samples from site 1 where both "beach bubble" sand and the corresponding bulk sand sample from across the beach were collected. In the latter case only the top 2cm of sand were collected for closer comparison with the "beach bubble".

slope. The "beach bubbles" were relatively few. They developed at and within 60cm of the swash (froth) line. Immediately after the backwash, and as soon as infiltration allowed, the "beach bubbles" appeared. The "beach bubbles" must therefore form during backwash. This observation has been confirmed by B.G. Jones (pers. comm., 1980). The "beach bubbles" may protrude above the water surface at the final stage. If minor air escape occurred (to potentially develop a structure like a sand volcano) the "beach bubbles" tended to disintegrate to very minor watery depressions during backwash. It is possible that the "beach bubbles" develop by air entrapped in the sand ahead of subsurface water rising up the beach below (and presumably just seaward of) the advancing swash (cf. Emery, 1945 — although the Illawarra beaches were apparently wetter than those studied by Emery). On one occasion on Corrimal beach large "beach bubbles" (to 150mm diameter) which had formed on a very shallow (1° to 3°) swash slope could be collapsed by foot, with consequent noticeable effects around the structure — the sand out to a radius of approximately 100mm was seen to be slightly uplifted by the air expelled from the "beach bubble". On Fairy Meadow beach (and on other beaches) the "beach bubbles" were destroyed by the next wave, presumably by collapse of the domed cavity by the added weight of water and especially by reduced shear strength of the wetted sand, especially in the crust (thus presumably allowing air to escape). The next group of "beach bubbles" then developed in the same sand but in different sites at or near the swash line.

The sand of the "beach bubbles" is sufficiently well-sorted and packed to maintain a cavity even during draining of water — i.e. earliest stages of drying. It is suggested that the gas (air) is trapped in the wet sand, and hence causes doming, because there is still a sufficient hydrostatic head above the sand to prevent gas escape. The gas entrapment and uplift phase generally lasted only about 10 seconds — 5 seconds of swash and 5 seconds of backwash. Such a time span would presumably allow the water to percolate by as much as 30mm into the sand, although this penetration would depend on sand size, sorting and packing (and presumably permeability) as well as on the time between wettings.

DISCUSSION

The "beach bubbles" appear to be transient and are not likely to be preserved. This transience is due to the nature (and place) of their development and destruction/replacement. Apparently they form by gas (presumably air) attempting to escape from the sand wetted by the swash — but apparently only during backwash and during infiltration. Preservation could be possible — for example in the situation observed on Bombo beach, where the high tide swash (storm waves) reached almost across the entire beach because the shoreward two-thirds consisted of a slightly landward-sloping back-berm. Should such a beach configuration be maintained (which is possible for several weeks) then beach rock development could preserve "beach bubbles" (which would presumably take longer than several weeks). Inflow of fluvial/coastal lagoon clayey sediments would presumably wet and collapse the "beach bubbles" and thus preclude preservation. (Clayey sediments had been deposited on Bombo beach, although it is not implied that any of the preservation possibilities was active on Bombo.) However, on Corrimal beach "beach bubbles" have been observed temporarily preserved in sand dried after a drop in tide, the crust being slightly cemented by dried ?salts.

Owing to their transience (for example the crust and cavity would generally collapse quickly during burial loading) it is not surprising that "beach bubbles" are not illustrated as such by, for example, Pettijohn and Potter (1964), Conybeare and Crook (1968) or Reineck and Singh (1975). "Beach bubbles" are unlike sand or mud volcanoes, having no craters. It is possible that this is the case for "beach bubbles" because the volume of gas attempting to escape tends to be insufficient to cause rupture. Thus the "mounds" described by Kindle (1916) and similar features described by later authors formed differently from the Illawarra "beach bubbles". The features illustrated by Smith (1971) were grossly similar in morphology to the "beach bubbles" but were much larger and formed in a very different fashion.

TABLE 1

STATISTICAL DATA (AFTER FOLK, 1974) RELATING TO SAND OF "BEACH BUBBLES" ON THE ILLAWARRA COAST

| Sample No. | Graphic Mean $M_Z$ (Grainsize) $\phi$ | Inclusive Graphic Standard Deviation $\sigma_I$ $\phi$ | | Inclusive Graphic Skewness $Sk_I$ | | Graphic Kurtosis $K_G$ | |
|---|---|---|---|---|---|---|---|
| 1 | 1.48 | 0.439 | well-sorted | -0.054 | near symmetrical | 1.05 | mesokurtic |
| 1m | 1.40 | 0.326 | v.well-sorted | +0.087 | near symmetrical | 1.08 | mesokurtic |
| 2 | 1.35 | 0.280 | v.well-sorted | -0.042 | near symmetrical | 1.06 | mesokurtic |
| 3 | 1.41 | 0.492 | well-sorted | -0.279 | coarse-skewed | 1.13 | leptokurtic |
| 3m | 1.47 | 0.347 | v.well-sorted | -0.076 | near symmetrical | 1.09 | mesokurtic |
| 4 | 1.48 | 0.426 | well-sorted | -0.048 | near symmetrical | 1.07 | mesokurtic |
| 5 | 1.28 | 0.363 | well-sorted | -0.012 | near symmetrical | 1.06 | mesokurtic |
| 5m | 1.30 | 0.342 | v.well-sorted | -0.033 | near symmetrical | 1.17 | leptokurtic |
| 6 | 1.70 | 0.346 | v.well-sorted | +0.003 | near symmetrical | 0.89 | platykurtic |
| 7 | 1.73 | 0.352 | well-sorted | -0.037 | near symmetrical | 0.91 | mesokurtic |
| 8 | 1.57 | 0.336 | v.well-sorted | -0.160 | coarse-skewed | 1.08 | mesokurtic |
| 8m | 1.53 | 0.362 | well-sorted | -0.172 | coarse-skewed | 1.09 | mesokurtic |
| 9 | 1.37 | 0.389 | well-sorted | -0.182 | coarse-skewed | 1.07 | mesokurtic |
| 9m | 1.34 | 0.434 | well-sorted | -0.330 | strongly coarse-skewed | 0.903 | mesokurtic |

NOTES: The suffix "m" signifies a bulk (or multiple) sample (see text for description and Fig. 1 for locations of sample sites).

Emery (1945) described, inter alia, "sand domes" which were apparently very similar to the "beach bubbles" of this study. The term "beach bubble" is preferred here because of the implied process of formation. Similarities between the observations of Emery (1945) and those reported here include their morphology and size, and the beach slope. However, as noted above the sand of Illawarra "beach bubbles" and of the overall beach are not readily distinguishable — whereas Emery (1945, p. 40) observed "Almost invariably the sand domes are restricted to beaches having thin layers of coarser sand alternating with layers of finer sand.". In some Illawarra "beach bubbles" the crust appeared coarser, but this could have been caused by aeration above the air cavity. In this study the "beach bubbles" formed at various tide stages, but Emery (1945, p.47) observed the domes "on the highest part of a beach reached by high tide."

The "mounds" illustrated and described by Trefethen and Dow (1960, fig. 15, pp. 598 and 602) are similar to the "beach bubbles" described here. However, figure 15 of Trefethen and Dow (1960) showed the "mounds" to have slightly steeper edges or slopes (cf. Fig. 2) and perhaps for this reason some "mounds" in their figure were smaller than the "beach bubbles". Another (possible) difference is that Trefethen and Dow (1960) made no reference to internal features. Trefethen and Dow (1960, p. 602) reported that the "mounds were observed to form in front of the advancing tide" although their figure 15 showed several mounds spread over an area associated with mineral streaking or lineation (which could have developed during backwash). If the "mounds" form in the way suggested by Trefethen and Dow (1960) then the "beach bubbles" of the Illawarra beaches form differently — just below the swash line during and immediately after backwash.

Hoyt and Henry (1964) described sponge-like bubble development in sand beaches — a texture rather like light, porous bread. That development created a distinctly different texture from that of the "beach bubbles", and also involved disruption of layering. The fluid-escape structures described by, for example, Lowe (1975, pp. 166-175) and Johnson (1977) are also distinctly different in that disruption of sands occurred. In the Illawarra "beach bubbles" no significant disruption of any layer that may be present was observed.

## CONCLUSION

Hollow transient swellings, with a crust of sand, are developed as "beach bubbles" on quartz sand beaches of the Illawarra district of New South Wales. These "beach bubbles" are between 50mm and 150mm in diameter. They develop near the

top of the swash during or immediately after the backwash has returned, and probably before significant infiltration has occurred. Development is apparently in response to doming by air entrapped in the damp sand ahead of advancing water associated with the swash — provided the within-sand air pressure exceeds the ambient external pressure and the damp sand has sufficient shear strength.

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Note added in proof

A.M. Clarke (pers. comm., 1981) has "loaded" beach bubbles with pebbles. The maximum weight supported by a beach bubble was 117 gm.

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# An Early Cretaceous Age for Subsurface Pilliga Sandstone in the Spring Ridge District, Mooki Valley

HELENE A. MARTIN

ABSTRACT. The palynology of the supposedly Jurassic Pilliga Sandstone at Spring Ridge, one of the most easterly outcrops of this unit, shows that it is Early Cretaceous, and not Jurassic. Lithologically and hydrologically, the sandstone at Spring Ridge is very like the Pilliga Sandstone. Two likely explanations for this discrepancy are discussed.

Some Tertiary assemblages, most likely Late Oligocene have been found beneath the basalts of the Liverpool Range Beds.

## INTRODUCTION

The Spring Ridge district is just south west of the area in the Mooki River Valley reported in Martin 1979, but the stratigraphic palynology is entirely different.

A sandstone outcrop at Spring Ridge is mapped as ? Jurassic Pilliga Sandstone with smaller areas of the underlying Jurassic Purlawaugh Beds. There are a number of outcrops of the Tertiary Liverpool Range Beds which include basalts. The valleys are filled with Quaternary alluvium (1:250,000 Geological Series, Tamworth Sheet SH 56-13). Samples from bores in this region were received from the Water Resources Commission of New South Wales with a request for confirmation of the Jurassic age, but a palynological examination shows that the sandstone is Early Cretaceous and not Jurassic. Some Tertiary assemblages, trapped beneath the basalts, were also found. This paper reports the stratigraphic palynology of the Spring Ridge bores.

## GEOLOGY

The bore logs show an overlying clay and gravel layer (see Figs. 1,2). Sandstone is encountered at 28m in Bore 30315 which is on the flanks of the ridge, but elsewhere it is much deeper. Shale and siltstone overlie the sandstone in Bore 36334. Basalts are encountered in the other bores.

The sandstone is white to grey, mainly coarse grained and porous. Thin layers of shale, siltstone and coal are encountered throughout. Lithologically and hydrologically, it has all the characteristics of the Pilliga Sandstone which is the major aquifer of the Great Australian Basin. There is no doubt that the Pilliga Sandstone is Jurassic in age, but the nearest palynological dating is some 90-100km to the north west of Spring Ridge. Other aquifers occur in the "Upper Blythesdale Group" (Jurassic and Early Cretaceous) and the "Rolling Downs Group" (Cretaceous, Hind and Helby, 1969). However, the nearest occurrence of the Cretaceous is some 120km to the NNW (1:250,000 Geological Series, Narrabri Sheet SH 55-12).

The basalts from the East Liverpool Volcano have been potassium – argon dated by Wellman and McDougall (1974) and they are Eocene and Oligocene. However, there were a number of flows and the samples for dating were taken from the surface, some 60km to the south east, so it is impossible to trace the relationship, if any, from the dated basalts to the subsurface basalts in these bores.

## SAMPLING

All of the bores yielding Early Cretaceous assemblages were cored. Samples for treatment were taken from the centre of the core. The minor shale and coal bands in the sandstone, often no more than 1cm thick, were selected. The Tertiary assemblages come from cuttings.

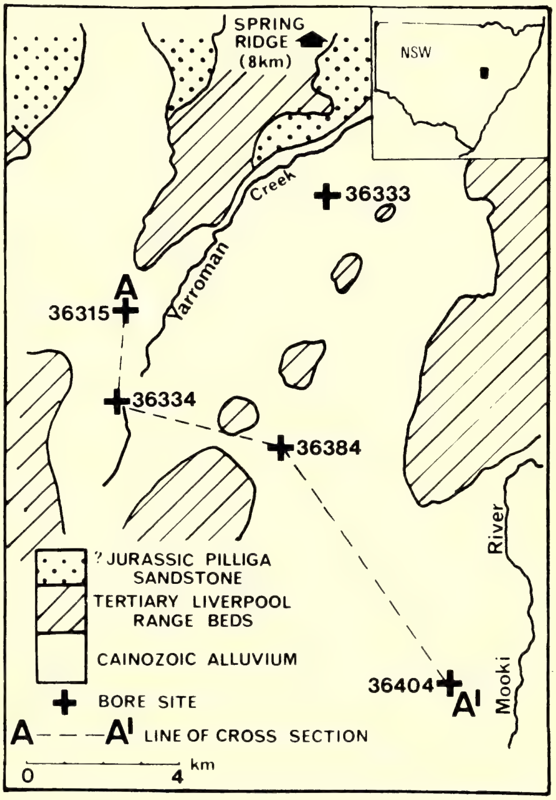


Fig. 1 Spring Ridge locality map. Outcrops from 1:250,000 Geological Series, Tamworth Sheet SH 56-13.

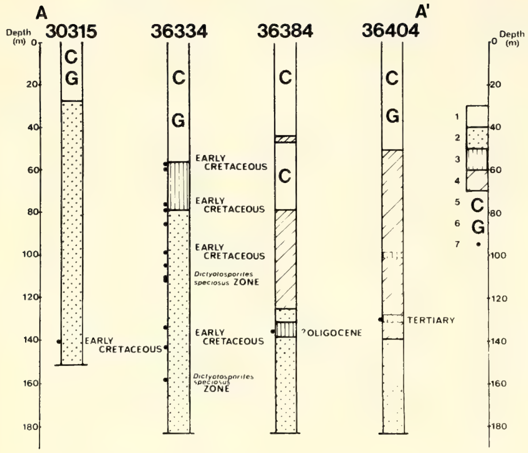


Fig. 2 Correlation of bores: 1. Predominantly red, yellow, brown alluvium. 2. Sandstone. 3. Grey siltstone and shale. 4. Predominantly basalts, often with frequent clay bands. 5. Clay. 6. Gravel. 7. Palynological sample.

## PALYNOSTRATIGRAPHY

Two ages are involved here, Early Cretaceous and Tertiary.

The Early Cretaceous assemblages contain the diagnostic species *Dictyotosporites speciosus*, *Aequitriradites spinulosus*, *Contignisporites multimuratus*, *Foraminisporites wonthaggiensis* and *Schizosporis reticulatus* which collectively indicate the *Dictyotosporites speciosus* Zone of Neocomian – Aptian age (Dettmann, 1963; Dettmann and Playford, 1969). Other species which are commonly accepted as exclusively Cretaceous forms are also present, viz: *Cicatricosisporites australiensis*, *Fovetriletes parviretus* and *Murospora florida*. Forms which range from Late Jurassic into the Early Cretaceous, e.g., *Contignisporites cooksonii* are also present, but no unequivocal Jurassic species have been found. The species identified in selected samples are shown in Table 1.

The diagnostic species are not common and they are lacking from a number of the samples examined. The quantitative aspects, however, indicate that all of the samples are the same age. *Baculatisporites comaumensis*, *Lycopodiumsporites*, spp. and *Cyathidites australis* are the most common forms. Of the gymnosperms, *Microcachryidites antarcticus* and *Podocarpidites* spp. are the most common but *Araucariacites australis* and *Tsugaepollenites* spp. are also frequently encountered. No dinoflagellates are present, indicating fresh water deposition.

Early Cretaceous assemblages have been identified in twelve samples selected from a core from 58m to 158m through the sandstone and its overlying shale and siltstone. Assemblages of the same age have been found at depths of over 100m in two of the other bores.

The Tertiary assemblages contain abundant *Nothofagus* spp. and only three species of *Proteacidites*, *P. ivanhoensis* being the most common. *Phyllocladidites mawsonii* was not identified, and the content of *Myrtaceidites* spp. is low. These features collectively indicate the middle part of the *Proteacidites tuberculatus* Zone (Stover and Partridge 1973). The most likely age is late Oligocene, although assemblages such as these range into the Early Miocene. Only two Tertiary assemblages have been encountered, one very poorly preserved with insufficient evidence to place it in a zone. For the purposes of this paper, both assemblages are assumed to be the same age. The two Tertiary assemblages occur at depths of over 130m where the basal sandstone is reached at approximately 140m.

## DISCUSSION

There is no doubt that the Spring Ridge sandstone closely resembles the Pilliga Sandstone on lithologic and hydrologic grounds, but it is not Jurassic, the accepted age of the Pilliga Sandstone. There are two possible explanations for this discrepancy:

1) The Pilliga Sandstone is time transgressive. Given the large area covered by this unit, this explanations is entirely feasible.

2) This is not the Pilliga Sandstone but one of the overlying units which has become more sandy towards the margin of the basin. The Early Cretaceous sediments to the north in the Surat Basin are marine whereas these are fresh water. It will require further evidence to resolve this problem.

In the Tertiary, most likely the Late Oligocene, Spring Ridge must have been a sandstone ridge extending some 100m above the valley to the south west. In the valley, local swamps, bogs, etc., provided the natural pollen traps necessary for pollen preservation. Successive lava flows from the East Liverpool Volcano filled up the valley, preserving the sediments containing the Tertiary pollen. Judging from the outcrops of basalts, the lava flows probably covered all of the sandstone ridge as well. Subsequent erosion has exhumed the sandstone ridge and carved out the present valley.

## ACKNOWLEDGEMENTS

This work was funded by the Water Resources Commission of New South Wales who also provided the samples.

I am indebted to Dr. J.N. Cramsie for discussions on the problems herein. Mr. G. Gates of the Water Resources Commission of New South Wales read the manuscript. Mr. P. Gadek prepared the diagrams.

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TABLE 1

SPRING RIDGE BORES

+ Present ++ Abundant

| | Bore & Depth (m) | 36334 | | 36333 | 36315 |
|---|---|---|---|---|---|
| | | 57.9 & 59.4 | 110.6 & 111.2 | 143.2 & 158.5 | 112.8 | 140.2 |
| **Gymnosperm pollen** | | | | | |
| *Alisporites grandis* (Cookson) Dettmann 1963 | | | + | + | + |
| *A. similis* (Balme) Dettmann 1963 | | + | + | + | |
| *Araucariacites australis* Cookson 1947 | | + | + | + | + |
| *Classopollis* cf *C. classoides* Pflug emend Pocock & Jansonius 1961 | + | | | | + |
| *Ginkgocycadophytus nitidus* (Balme) de Jersey 1962 | + | | | | |
| *Microcachryidites antarcticus* Cookson 1947 | + | + | + | + | ++ |
| *Podocarpidites* spp. | + | + | + | + | |
| *Tsugaepollenites dampieri* (Balme) Dettmann 1963 | + | + | + | + | + |
| *T. trilobatus* (Balme) Dettmann 1963 | | | + | | |
| **Spores** | | | | | |
| *Aequitriradites spinulosus* (Cookson & Dettmann) Cookson & Dettmann 1961 | | | | + | |
| *Baculatisporites comaumensis* (Cookson) Potonié 1956 | ++ | + | ++ | ++ | ++ |
| *Ceratosporites equalis* Cookson & Dettmann 1958 | + | + | | | |
| *Cicatricosisporites australiensis* (Cookson) Potonié 1956 | + | | | | |
| *Contignisporites cooksonii* (Balme) Dettmann 1963 | | | + | | |
| *C. multimuratus* Dettmann 1963 | | | + | | |
| *Cyathidites australis* Couper 1953 | ++ | ++ | + | + | + |
| *C. minor* Couper 1953 | + | | + | | |
| *Dictyophyllidites crenatus* Dettmann 1963 | | | + | | |
| *Dictyotosporites speciosus* Cookson & Dettmann 1958 | | + | + | | |
| *Foraminisporis dailyi* (Cookson & Dettmann) Dettman 1963 | + | + | | | |
| *F. wonthaggiensis* (Cookson & Dettmann) Dettman 1963 | | | + | | |
| *Fovetriletes parviretus* (Balme) Dettmann 1963 | + | + | | | |
| *Gleicheniidites* cf *G. circinidites* (Cookson) Dettmann 1963 | | | + | | |
| *Klukisporites scaberis* (Cookson & Dettmann) Dettmann 1963 | | + | + | | + |
| *Leptolepidites verrucatus* Couper 1953 | | + | + | | |
| *Lycopodiacidites asperatus* Dettmann 1963 | + | | | | |
| *Lycopodiumsporites austroclavatidites* (Cookson) Potonié 1956 | ++ | + | + | + | ++ |
| *L. reticulumsporites* (Rouse) Dettmann 1963 | | + | + | + | + |
| *Murospora florida* (Balme) Pocock 1961 | + | + | | | |
| *Neoraistrickia truncatus* (Cookson) Potonié 1956 | + | | | + | |
| *Osmundacidites wellmanii* Couper 1953 | + | + | | | |
| *Reticulatisporites pudens* Balme 1957 | | + | | | |
| *Schizosporis reticulatus* Cookson & Dettmann 1959 | + | + | | | |
| *Stereisporites antiquasporites* (Wilson & Webster) Dettmann 1963 | + | + | | | |

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# Address By His Excellency The Right Honourable Sir Zelman Cowen, A.K., G.C.M.G., G.C.V.O., K.St.J., Q.C., Governor-General of the Commonwealth of Australia, on the Occasion of the Annual Dinner of The Royal Society of New South Wales at the Hilton Hotel, Sydney, Friday, 6 March 1981

COWEN, HIS EXCELLENCY SIR ZELMAN, A.K., G.C.M.G., G.C.V.O., K.St.J., Q.C.

It is a great pleasure to attend the Annual Dinner of this distinguished and long established scientific Society. Your President in writing to invite me said that the Society was established in 1821, with the Governor, Sir Thomas Brisbane, as a member. I have read a little of the history of the Society. A 1961 essay by a former President tells that the 1821 Society had the grand title of "The Philosophical Society of Australasia", no less, and was formed "with a view to inquiring into the various branches of physical science of this vast continent and its adjacent regions". That, if I may say so, gave a restricted interpretation to the broad word, "philosophical", and while later descriptions of the Society's activities and objects have held open a wider prospect, your 1961 historian records that "art, literature and philosophy have had but scant attention in the proceedings of the Society which has concerned itself principally with various aspects of pure and applied science".

In 1974 at the dinner of the Society, Sir Roden Cutler spoke of the association of Governors with this Society. Sir Thomas Brisbane, already mentioned, had scientific interests, notably in astronomy, and he took an active interest in the earliest Society's affairs. Later, in the mid-nineteenth century, Sir William Denison, who, Sir Roden tells, was an engineer of some merit, gave the first paper to the remodelled Philosophical Society of New South Wales in 1855. Sir Roden says that Denison continued to write articles for the Philosophical Society, and regarded this work as compensating for what he described as the "work (of government) being taken out of my hands" by the formation of a Legislative Council.

Your contemporary activities continue in the areas of basic and applied science. Your President in writing to me says that my previous experience was in many ways akin to the aims of the Society in relating science and scholarship to the general community. Certainly, as a Vice-Chancellor of Australian universities, I had many involvements in scientific matters, and in this Office I have had many opportunities to speak on themes associated with science and technology. When I undertook the daunting task of delivering the Jubilee Oration to the Australian Academy of Science, on the occasion of its twenty-fifth anniversary, I said that it was reported that Francis Bacon had talked science like a Lord Chancellor. If it was true, he certainly claimed a knowledge and understanding of contemporary science and spoke with confidence. I claim no such knowledge, and while, like him, I am a lawyer, I am no Lord Chancellor (a Vice-Chancellor is something different), and my qualification and capacities to "talk science" are very poor.

Since I have started in this way, I can, perhaps irrelevantly, tell you that the title "Vice-Chancellor", as well as applying to university functionaries, has had and has a place in the English judicial system. Long ago, two Vice-Chancellors were sitting in adjacent courts. One was Vice-Chancellor Malins, and a discontented litigant threw an egg at him which, I think, missed. Sentencing this character for contempt of court, Malins remarked that he supposed that it was really intended for his fellow Vice-Chancellor, Bacon, who was sitting in the adjacent court.

Perhaps I can pursue briefly with you some of the themes related to science and technology with which I have been concerned. There are great difficulties in understanding and mastery; the late Lord Snow wrote long ago now of the two cultures, the science-based and the non-science based, and while his views have provoked argument, we can all understand what Robert Oppenheimer meant when he spoke of a thinning of common knowledge. Francis Bacon wrote copiously on many subjects, including science. It was a time when confidence in the capacity of a man to compass the whole of human knowledge was high, and this persisted long after. A man could feel comfortable in the description of a polymath. He could have some confidence in his claim to grasp the greater part of what was known to man. It is not so in our time.

The growth of scientific knowledge, and the development and applications of technology proceed at great speed. The social and human applications of this are very significant. When I spoke to the World Computer Congress late last year, I pointed out that the computer had made an immense impact, world-wide, within a short space of time. The first commercial computer was brought into service in 1951, thirty years ago. In 1964 it was in a museum. Within a generation (a human generation) the nature of computers has undergone revolutionary change. From bulky, expensive, unreliable, slow limited-use- "playthings of scientists", they have become small, cheap, fast and reliable, and they find unlimited applications in enterprises large and small. It was thought at one time that perhaps each major advanced nation might have a limited number of computing machines. Now they are within the comparatively easy reach of individuals. The Myers' Committee on Technological Change in Australia spoke of renewed concern about the impact of new technology on the structure of work and society, arising out of the rapid and recent development of microelectronic devices and their incorporation in products which have spread extensively. The Committee saw no signs of a slow-down in the development and application of this technology; each stage of development made

microelectronic circuits more complex, more reliable, less expensive. Microelectronic technology has the potential to permeate to some degree very many fields of human endeavour. The Myers' Report quoted a statement that "this development points to the advent of the most remarkable technology mankind has ever devised".

Again, when I spoke to the Academy of Science almost two years ago, I discussed, within the poor limits of my understanding, current issues associated with research on recombinant D.N.A. That was at a time when there was an international debate on risks and dangers associated with such work. The arguments had given rise to deep concern on the part of scientists that freedom of enquiry might be threatened. Lord Todd, as President of the Royal Society, said that "ominous voices have been raised claiming that limits be set to scientific enquiry". He protested, in the context of the research of which I have been speaking, that there had been confusion and a "raising of the spectre of the production of Frankenstein-like monsters". There is an interesting and, I think, an important debate on issues of constraints, and within the limits of my understanding I sought to raise these issues in my address to the Academy of Science.

It is interesting to read an account of recent developments in these areas. I quote from a recent paper on "Future Prospects for Basic Science in Medicine" by a distinguished American medical scientist:

> "It seems only yesterday that cell biology was the purest and most basic of all fields in biomedical research in constant need of defence before skeptical congressional sub-committees, hard to justify for taxpayers' funds except on grounds of rather vague prospects of usefulness years off. Now, almost overnight, it looks like a way to make lots of money. The big pharmaceutical houses are already doing cell biology in great vats while tiny new corporations are sprouting everywhere at the edges of university towns for the development of innovate and patentable technologies. Cells are not just useful, they are about to yield profits.
>
> "...Wall Street analysts keep tabs on the monoclonal antibodies made by hybridomas and on the new plasmids for recombinant D.N.A. research for making things like insulin and interferons as closely as on the transistor circuits of a generation ago ... the techniques for putting novel working parts inside cells, or for exchanging the nuclei and other bits of machinery between cells, have become almost as sophisticated and precise as solid-state physics and there is no end to the list of possible applications.
>
> "So it sounds as if basic research has suddenly turned into applied science before our eyes and from here on we might expect quick profits all over the place..."

Computer and biological science and technology open up a great range of issues and concerns. For society and for the lawyer, there are many and complex problems. Julius Stone wrote recently that one part of the explanation of the sharp and ubiquitous confrontations of our own age, and for the tendency for justice to split into competing versions, certainly lies in the headlong rate of social change, powered above all by accelerated technological change. This was underlined in an address by Mr Justice Michael Kirby, the Chairman of the Australian Law Reform Commission, on "Reforming The Law". He made the point that in our time pressures for change, including legal change, are very great. Science and technology, in particular, present many challenges to laws developed in earlier times, and the changes they bring to society frequently require the radical reconsideration of established legal rules.

He illustrated this by reference to specific matters, with which the Law Reform Commission is and has been concerned. One is human tissue transplants, often depending on the transfer of non-regenerative organs and tissues. It raises a complex of problems in transplants from a "dead" to a living person. This involves a need to define "death". There are problems as between living persons involving issues, among others, relating to consent. Questions of consent in this area and in the broader areas of human experimentation are difficult and complex. Advances in biomedical science and technology may depend significantly on tests applied to living human subjects; man becomes the ultimate "animal of necessity". Out of wartime experiments and work done by Nazi doctors on captive human subjects, there came an awareness of the needs for rules and controls, certainly for co-operation between physicians, lawyers and others to protect the human subject and to formulate as carefully as possible the conditions under which human experimentation might take place. It has been attempted at international and national levels. What lies at the heart is the notion of an "informed consent", and this is not easy to identify with precision. What underlies it is the principle which seems to me plainly right, that the human being must never be treated as a depersonalised thing; for this reason we seek an autonomous and informed consent. Again, we have problems associated with the test-tube baby issue; legal problems, and as one explores the possibilities, it may be problems of a broader character. I recall the comment of a writer reviewing the major events of 1978:

> "The most important birth of the year (leaving aside the little Mozarts who have not yet made themselves known) was of Louise Brown, conceived in a laboratory dish. That fertilization was less important as an achievement than as an omen; in biology, as in politics, power is expanding faster than our ethical understanding."

Mr Justice Kirby also referred to questions associated with computers and their development: they have revolutionised the assembly, supply, manipulation and distribution of information. This includes highly personal material, so that important questions relating to the privacy of the individual, an important value in a free society, are raised. He points out that computers can

store vastly increased amounts of information, and retrieve it much more quickly, and at much lower cost than manual filing systems. They can integrate data supplied for differing purposes; they are susceptible to centralised control, and often produce their material in a form unintelligible except to the trained expert. Such developments and the proliferation of computers throughout society and the economy present many problems for the legal system. These include issues of privacy, and problems in the criminal law through manipulation and theft.

Indeed, technology generates problems for the protection of privacy in a variety of ways. The first significant and comprehensive examination of legal issues relating to privacy was published in the United States in the 1890's. That in turn arose from publication of matter of a personal and private character in the popular press: the problem assumed significant dimensions because of the development of a new technology which produced mass circulation newspapers at a very cheap price. There are also issues relating to surveillance. The original eavesdropper, no doubt, listened furtively under the eaves; then the telephone and telegraph gave him new opportunities to tap, and opportunities beyond imagining became available with the proliferation of modern "wire-less" listening and surveillance devices. I spoke of such matters as these when I gave the Boyer Lectures on "The Private Man" in 1969, and I said then that "the private man may find himself naked and uncertain in a psychological prison fashioned by a complex technology, not knowing when and by whom he is being watched or overheard".

There are many other illustrations of the way in which new technology can outdate the law. A well established technology exposes the deficiencies of a copyright law designed to protect the interests of publishers and writers of books. When I was a student, I might copy out by hand extracts from books and printed journals; nowadays, copying machines are freely available and very extensively used. A recent Commonwealth committee has examined and reported on the problems this raises. Our copyright law was certainly devised without any such technology in prospect.

These are a few illustrations of the problems posed for society and the law by the development of technology. In various contexts, there are calls for a moratorium, a halt. Lord Ashby, writing in the mid-seventies, noted significant changes in the intellectual and cultural climate of our time. For generations, he says, it has been taken for granted that all that can be done in science and technology must be done; the new ethic emerging is that somehow man must agree not to do all that he is capable of doing.

I have seen applications of this in contemporary discussions of the ethics, the wisdom and the propriety of certain scientific and technological work. I sought to explore some of these issues in the address to the Academy of Science on "What Are the Constraints"? Scientists with the support of a noble and convincing history strongly resist the imposition of any curbs on scientific research and investigations. They draw a distinction between scientific investigation and experimentation, and its technological applications. Yet it is said that in our day the distinction and separation are hard to maintain because application follows so closely on the heels of thought that the long established immunities granted to freedom of thought cannot so readily be agreed to in the context of action. There are hard questions to be carefully debated and sensibly resolved in a free society.

It is the case that a society which is profoundly affected by a rapid and continuously developing technology requires a mechanism which will allow for appropriate legal change and adjustment. Mr Justice Kirby argues, I think persuasively, that there have to be appropriate mechanisms for law reform to adapt the law to changing circumstances and conditions which are themselves the product of a fast developing technology. "If nothing is done to adjust the legal system to (these) scientific developments, things will not just remain the same. Inconveniences and sometimes perceived injustices (and I may add serious tensions) will occur because old rules of law have become irrelevant or positively obstructive, or because situations have arisen affecting members of society upon which current laws are perfectly silent."

I raise such questions as these with the hope that they may attract the interest of the members of a Society long committed to the consideration and discussion of questions of a scientific and technological character. There is, of course, so much more to be said, but not by me, on this agreeable occasion. I thank you for your hospitality.

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# History in Walls

G. S. Gibbons

ABSTRACT. Chronologies can be established for a wide variety of inorganic building materials from Colonial and Victorian times. The work requires co-operation between materials scientists, architects, historians, and archaeologists. Some of the changes followed on developments overseas, some from the particular range of materials available within the Colony, and some from the social environment of the times. Using physical, chemical, and mineral analysis of such materials as bricks, plasters and paints, materials studies link up with architectural documentation and research on historical archives, to provide a clearer understanding of both the social and architectural development of Australia.

## INTRODUCTION

This paper outlines the contribution that the study of wall materials can make to the historical interpretation of buildings. Some of the studies referred to were largely done with financial assistance of the NSW Heritage Council in a project assisted by Mrs. C.M. Bertles. Assistance has also come from many other sources, particularly from officers of the Historic Buildings Section of NSW Department of Public Works, and of the Heritage and Conservation Branch, NSW Department of Environment and Planning.

I will take it as self-evident that history is important: that in crudest terms a civilized community needs to plan ahead, and that you cannot know where you are going if you don't know where you've been!

How can study of old buildings help us to understand history? I think in three main ways:

1. Buildings tell us about technological development: what materials have been available and how they were used. The materials change as new sources are discovered or as trade patterns change. New applications may be imported, or they may show evidence of home-grown initiative, inventiveness, or plain necessity.

2. Buildings tell us about social development. The various rooms and fixtures show how people lived, what comforts and services they had, how they related physically to servants or tradesmen. The variation of design and workmanship at any one period shows the range of skills of tradesmen and the differences among various regions and social strata.

3. Buildings tell us about individual people, great or small: what their pretensions were, what they admired, whether they looked to the past or the future for inspiration. If they are famous people we may gain new insights into their personality. One family perhaps preferred the security of a solid home of modest appearance; another family might have build a most elegant facade with a cramped, jerry-built back section.

In some cases the study of materials contributes directly to these areas of understanding; in others the contribution is indirect. To explain how materials studies assist, it is useful to consider three separate aspects of the matter:-

a) The relationship between materials, building structure, and style.

b) Technological developments and their arrival in New South Wales.

c) Methods of analysing nineteenth century building materials.

In the following discussion, each of these three aspects will be exemplified by a single material - respectively bricks, paints, and mortars.

## BRICKS: PARTS AND THE WHOLE

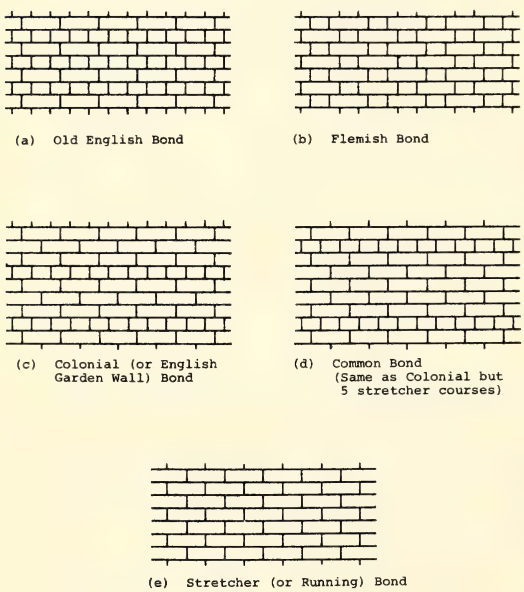
In examining an old building, it is possible to some degree to separate three features: the actual parts or materials used, the way they are assembled, and the form or appearance of the whole. I will refer to these aspects as the material, the construction, and the style.

To some degree, these aspects are related. There is little doubt that the processes of machine-made bricks (introduced from 1852 to 1884 in the Sydney area) led to more compact, stronger bricks of very uniform size. This in turn made possible the development of cavity walls, which are first known in Sydney at Sussex Street Public School in 1875, and became quite general by about 1895.

*
*Presidential Address delivered to the Royal Society of New South Wales at Science Centre, Clarence St., Sydney, on April 1, 1981.*

The newer style and construction can be contrasted with earlier building practices. The use of stone coigns at the corners of early brick buildings (including the first one built for Governor Phillip) was partly intended to compensate for the irregularity of the brickwork. Brick nog construction, in which bricks are used to fill the cells outlined by a timber framing, seems also to be partly a response to irregular brick dimensions: it seems to have been especially favoured where second-hand bricks, of variable sizes, were being used. The brick nog construction was used, mainly in internal walls, at least from the 1820's to the later nineteenth century.

The connection of materials and detailing is even more clear. The use of tuck-pointing in joints was essential for a clean attractive appearance with the irregular edges of hand-made bricks, but was only a refinement once sharp-edged machine bricks were readily available. It is likely that the gradually improving quality of bricks in the second half of the nineteenth century also allowed the progressive change from Old English bond to Colonial bond to American Common bond, which represents a gradual decrease in intrinsic strength of the bonding (Fig. 1).



(a) Old English Bond

(b) Flemish Bond

(c) Colonial (or English Garden Wall) Bond

(d) Common Bond (Same as Colonial but 5 stretcher courses)

(e) Stretcher (or Running) Bond

Fig. 1 Bond types as they appear on the face of a wall. Types (a) and (b) were used from the first years of the Colony of N.S.W.; (c) and (d) became popular in house walls about 1850 and 1870 respectively; and (e) is characteristic of the cavity wall, common from about 1890 onwards.

Bonding of bricks can involve far more human matters than the development of brick technology, for the weak but attractive Flemish bond was used by some architects right through into the 20th Century. Francis Greenway was a Flemish bond man, whereas the famous Horbury Hunt fifty years later used Old English bond almost exclusively, and some country towns reflect the preferences of the local builder in the bonds used in their buildings.

We have all seen houses around Sydney with face-bricks facing the street and commons on the other three sides, but it is interesting that as early as 1793, John MacArthur's Elizabeth Farm House was built with the attractive Flemish bond in the front facade, but with the simpler and easier (and also stronger) Old English bond elsewhere. Again, it is interesting to consider the wide variety of bricks found when the old Lawson homestead near Prospect, "Veteran Hall", was demolished some years ago. It seems almost certain that at least part of this house was constructed of second-hand bricks from several sources; though I have no idea whether any historical significance can be drawn from this.

The connection between brick quality and architectural style is more difficult to pinpoint, but Professor Max Freeland considers that the Queen Anne style became dominant in the Federation period partly, at least, because top-quality moulded bricks were readily produced by the new methods.

PAINT: TIME AND PROGRESS

In some areas, technological development on the other side of the world was occurring quite independently of events in Australia. If the materials involved were portable and not locally available, European developments could appear in New South Wales as fast as a ship could carry them. An example is in oil-paints, pigments for which were almost entirely imported throughout the nineteenth century. Indeed, there were Berger colours aboard the First Fleet, and early immigrants were frequently advised to include some house-paint products in their luggage.

Even waterpaints were largely imported, because no local gypsum was commercially available for gypsum until at least 1880. No white lead was made here until 1920, so the local primary pigments were restricted to lime and pipeclays. Indigenous ochres were also doubtless used, though their commercial exploitation appears to have been sporadic and desultory.

Thus the only local products used extensively, except for whitewashing, were the oils. Local "fish-oils" were in use by 1804. Linseed oil was imported at first, but local manufacture probably occurred well before 1850.

Ready-mixed paints were made here from 1850 onwards, but both the basic pigments and colours were still imported. White lead was the main base pigment, but I have found both zinc oxide and barium sulphate in paint layers between 1850 and 1900. Fig. 2 shows the development of white bases overseas; reliable application to the local scene awaits further research.

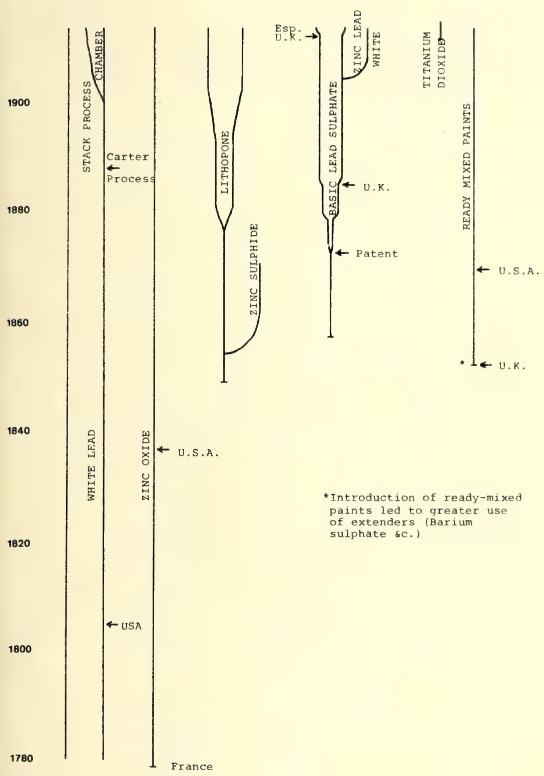



Fig. 2 Development of white base pigments up to 1910. Width of columns gives a broad indication of qualitative importance.

A great deal of useful research is waiting to be done, both in Europe and Australia, on the availability of different paints. However, it is already possible to define a large number of new developments useful in providing dates on Australian buildings, as the following brief list indicates:

| | |
|---|---|
| c.1897 | Artificial indigo |
| 1872 | Gas black replacing carbon black |
| 1870's | Lithopone ($BaSO_4$ + ZnS) and basic lead sulphate introduced |
| 1859 | Viridian green ($Cr_2O_3.2H_2O$) rediscovered |
| 1852 | First use of ZnS (white) |
| 1847 | Antimony vermilion ($Sb_2S_3$) |
| 1831 | Artificial ultramarine (Germany) |
| c.1830 | Chrome yellow ($PbCrO_4$) |
| 1814 | Paris green (Cu arseniate/acetate) |

In cases such as these, the value of materials analysis is solely to piece together the history of a building by limiting the relative ages of its parts. However, the potential value of paints does not end there. There are undoubtedly variations in the binders of oil-paints early on, which could be detected by analysing organic extracts from old paint film. Certainly "fish-oil" (probably from the elephant seal) was still being used in 1824, whereas by about 1840 linseed oil was general.

The locally-made whitewashes and distempers used as external paints were mostly made from local materials. They certainly changed, from pipe-clay base to shell-lime wash to rock-lime wash to kalsomines with gypsum plaster admixture. These changes require more study and will be complicated by imports; but because the succession of paints to a building is often preserved entirely in the multi-layer film, the successive changes may enable "anachronistic" imports to be recognized within the general succession.

MORTARS: ANALYSIS AND CONCLUSIONS

The earliest solid Sydney houses used loam or clay for mortar. The more important ones had an admixture of lime, made by burning shells gathered around the harbour foreshores.

Rock-lime was not available until after settlements were established in Port Stephens area and west of the Blue Mountains. Some rock lime from Mittagong was burnt in Sydney area (at Camden) in 1821, but shell lime was general until at least 1830, and was used in most situations until after 1850. There are reports of a shell-lime kiln operating at Lavender Bay (near Alderson St.) until the 1870's.

In Parramatta, the earliest sections of Government House (1790) and Elizabeth Farm House (1793) are bedded in loam, with no lime whatever. A few years later, however, extensions to both buildings were being constructed with weak lime mortars.

Meanwhile in Norfolk Island, no such shortages existed, as coral sand and sand-rock were readily available. Even the earliest buildings were provided with a rich lime mortar (1791).

About 1830, Sydney bricklayers started using clean sand in place of the former clay-rich river sand. This change was possibly related to the production of less porous bricks as pug-mills were introduced. In any case the change seems to be a fairly good time indicator.

At about the same time, external rendering underwent a change, also. Stucco finish, with Roman cement, replaced simple lime render. For stone walls, shell-lime and river-sand seems to have remained standard until about 1840, often with an admixture of coarsely broken, unburnt shell fragments.

It is not clear when Portland cement became available, though it first appears in Government

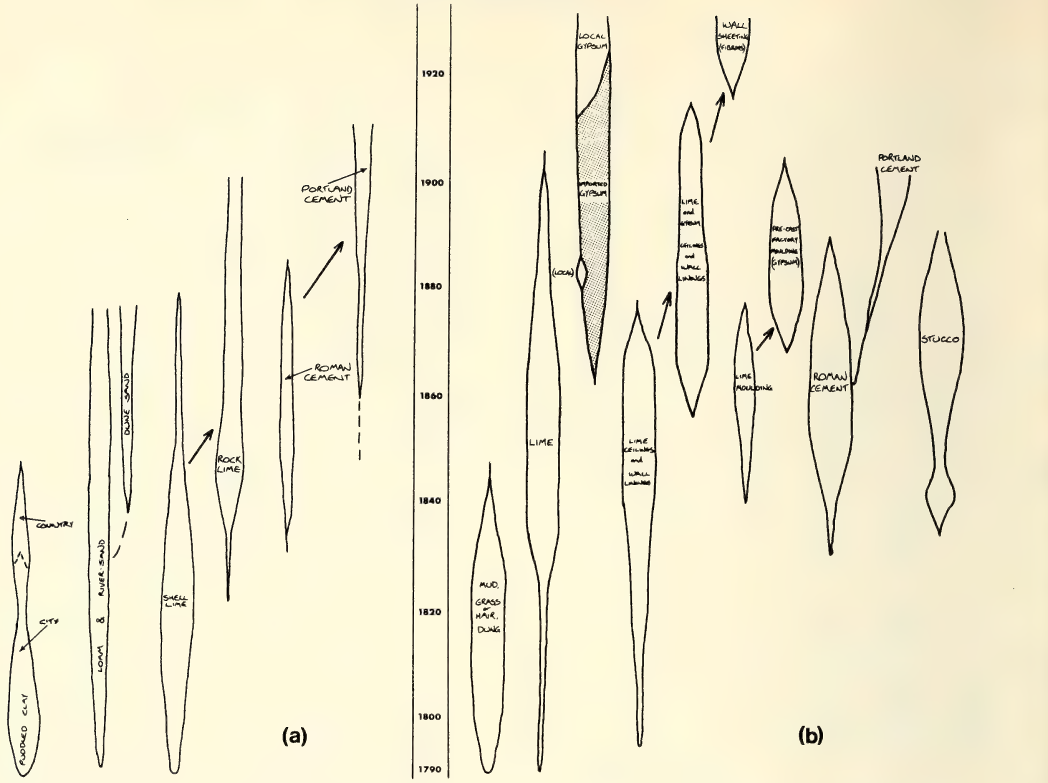
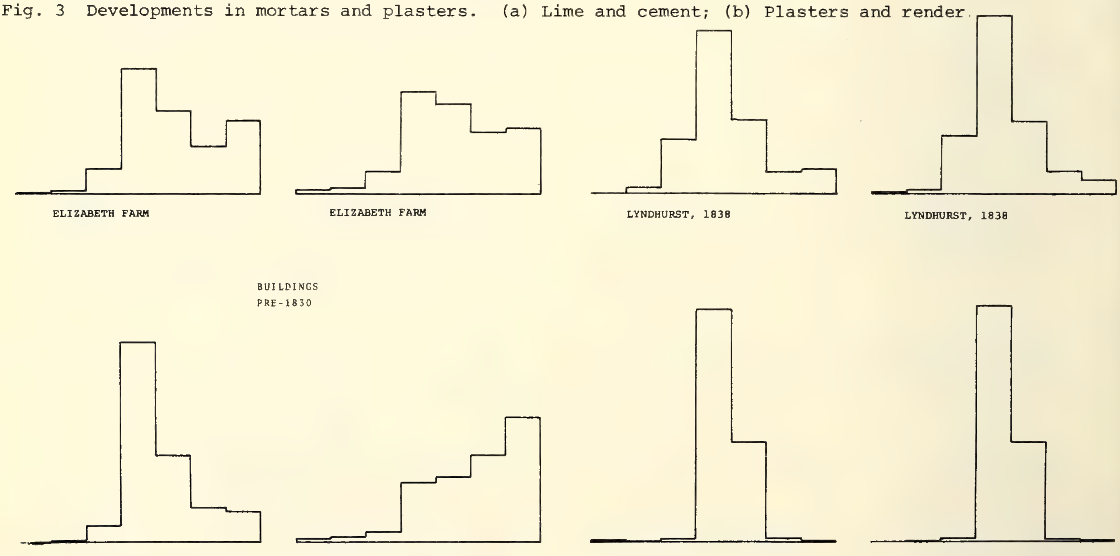



Fig. 3 Developments in mortars and plasters. (a) Lime and cement; (b) Plasters and render.



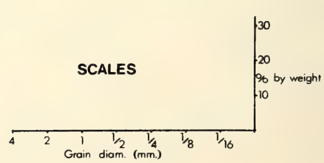




Fig. 4 Size distributions of mortar sands from six Sydney buildings. Note (a) the wide variety of loams and pit sands in the earlier (pre-1830) buildings; (b) the similarities in sands from different parts of Elizabeth Farm and Lyndhurst; and (c) the distinctive pattern found in the better-quality sands of the late nineteenth Century, exemplified by the last two diagrams.

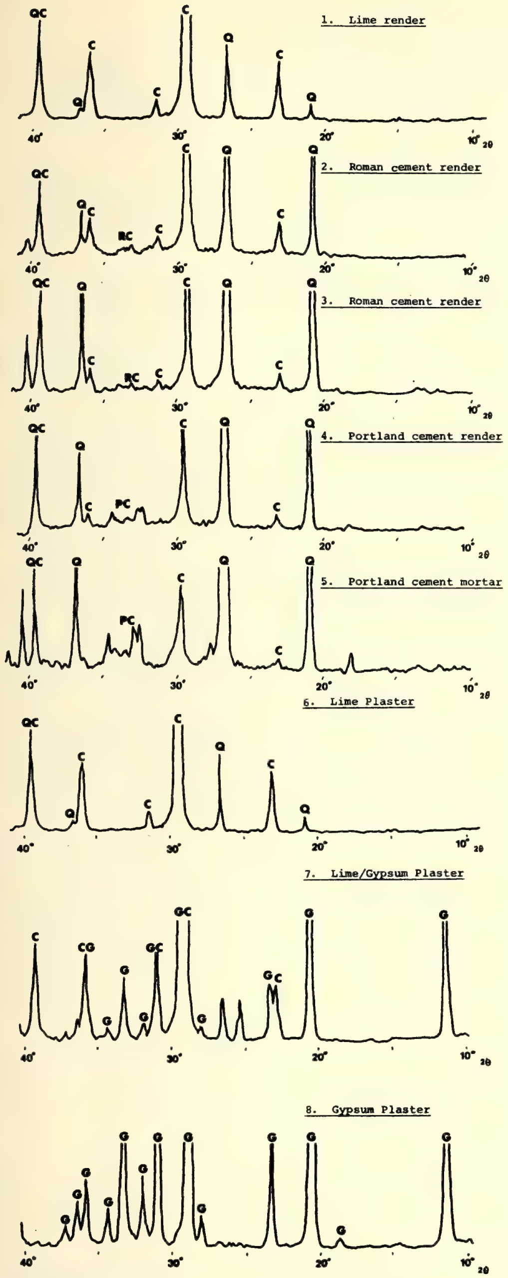



Fig. 5 X-ray diffraction charts, showing variation for different mortars and plasters. Each mineral component is characterized by a group of peaks, as marked; and the relative heights of the peaks indicate constituent proportion.

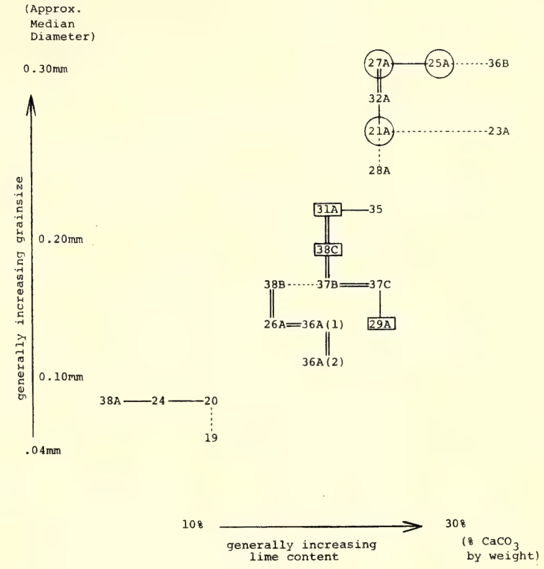



Fig. 6 A diagrammatic representation of relationship among plaster samples from Elizabeth Farm House, Parramatta. Linkage lines show degree of similarity of sands in terms of overall grainsize distributions. Circles are plasters with a setting-coat of lime-gypsum type; rectangles are plasters with setting-coat of lime-sand type. Four major groups are indicated, with more questionable correlations also shown. The diagram is essentially factual, but requires interpretation from on-site studies and documentary information on the building.

specifications in 1864. It was not made locally until 1890, and was used only in renders, not mortars, in the nineteenth century.

A summary of the general development of mortars and plasters is illustrated in Fig. 3.

The analysis of lime mortars is fundamentally simple, but flexibility is often necessary. The usual method is to treat a representative sample with hydrochloric acid, which dissolves away the lime. This enables calculation of the original proportions of lime to sand, and also releases the sand particles so that size-distribution can be found by sieving. Some typical size distributions are shown in Fig. 4.

The unburnt shell fragments in many of the early mortars create a problem; corrections must be made for this fraction in calculating results. For renders and platers, and for twentieth-century mortars, there may be other admixtures - Roman or Portland cement, or plaster of paris. These are most conveniently estimated by x-ray diffraction (Fig. 5).

In the case of Norfolk Island the entire mixture is acid-soluble, but the problem is rather different. Since all the nineteenth century rock is of similar composition it cannot be dated; but a later dating problem arises because of undocumented renovations in the last few decades. In this case, bagged lime from New South Wales was used. It happens that the indigenous lime contains appreciable magnesium not present in the later imports. As a result, the new work can be identified by the difference in degree of staining with a dye that affects only magnesian lime.

An example of analysis of materials is given in Fig. 5, in which a number of samples from Elizabeth Farm House are arranged according to median sand size and lime-sand proportions of the mix. The groupings have been found to be a useful addition to the other information available to archaeologists and architects.

## CONCLUSION

Materials studies do not provide magical keys, and their interpretation requires a broad understanding of the changes that have occurred in building technology. In sensible combination with other physical and documentary information, materials studies can contribute significantly to a total picture and can help avoid errors of interpretation. In the longer view, such studies elucidate our national history, and therefore help us to understand ourselves.

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Department of Applied Geology
New South Wales Institute of Technology
Broadway. NSW 2007

Presented at the 114th Annual General Meeting of the Royal Society of New South Wales held on 1st April, 1981.

INTRODUCTION

The Society has continued its activities at a satisfactory level, despite continued financial stringencies which have been somewhat worsened by changes in rules for the Commonwealth book bounty which now does not apply to the Society's Journal.

The retiring Council has set in train a review of all Society activities. This review will examine the changing needs of our membership, and the needs of potential members who may not be adequately attracted to the Society as it currently operates. It is the strong view of Council that the central aims of the Society remain relevant in the Community, and it is anticipated that the incoming Council will continue to develop the Society in ways most appropriate to achieve these aims.

Sir Roden Cutler retired from the office of Patron of the Society upon relinguishing his appointment as State Governor. Council is most grateful for Sir Roden's interest in the Society during his term of office. We are gratified that the office of Patron has been accepted by the incoming Governor of New South Wales, Air-Marshal Sir James Rowland, K.B.E., D.F.C., A.F.C.

MEETINGS

Council held 11 meetings during the year and dealt with all the business matters of the Society. Attendance of members of Council ranged from 8 to 16.

Nine general monthly meetings were held during the year together with the Liversidge Research Lecture. Abstracts of the lectures have been published in the Society's Newsletter. The average attendance at the general monthly meetings was 36 (range 25 to 44), which was somewhat higher than in 1979.

ANNUAL DINNER

The Annual Dinner was held at the Sydney Hilton Hotel on 6th March, 1981, and was attended by 109 members and guests. We were honoured by the presence of His Excellency the Right Honourable Sir Zelman Cowen, AK, GCMG, GCVO, K.St.J, QC, Governor-General of Australia, and Lady Cowen.

AWARDS

The following awards for 1980 were made:

| | |
|---|---|
| James Cook Medal | Professor Robert J. Walsh, A.O., O.B.E. |
| Edgeworth David Medal | Dr. Michael Anthony Etheridge |
| Clarke Medal | Not Awarded |
| The Society Medal | Mrs. Maren Krysko v. Tryst |
| Walter Burfitt Medal and Prize | Professor Hans A. Buchdahl, F.A.A. |
| Liversidge Memorial Lectureship | Dr. S.R. Johns |
| Archibald D. Olle Prize | Not Awarded |

SUMMER SCHOOL

The second Summer School on Earth Sciences was held over five days in January 1981. Fourteen students of various High Schools of the greater Sydney area took part.

The School of Applied Geology, University of New South Wales, was principal host of the Summer School. About 20 lecturers from Universities, Industrial and governmental organizations contributed to the success of the School. There were two excursions. One took place in the grounds of the University of Sydney and the Glebe area, studying applications of geology to the building industry. A second, full-day excursion went to the Southern Coalfields where both surface and underground installations were examined.

MEMBERSHIP

The membership of the Society at 31st March, 1981 was:

| | |
|---|---|
| Honorary Members | 13 |
| Life Members | 36 |
| Company Member | 1 |
| Ordinary Members | 324 |
| Associate Members | 39 |

PUBLICATIONS

Volume 113 Parts 1 and 2 of the Journal and Proceedings was published during the year. Parts 3/4 were delayed because of a fire at the printery but should be posted during April.

There were 10 issues of the Society's Newsletter. Council is most grateful to the authors of the short articles which are much appreciated by most of our members.

LIBRARY

There were a total of 184 requests for copying from the library, of which 4 percent were from members and 96 percent from other institutions, mainly Universities and Colleges (39%), private companies (24%) and Government Departments (21%).

Some 2166 items were received and processed from 380 institutions, mainly through Journal exchange.

Mrs. G. Proctor has retired from her position as an employee of the Society. Council has very gratefully accepted her offer to continue her work, s Honorary Assistant Librarian.

The Council expresses great regret at the recent death of Mr. Walter Poggendorff, for many years our Honorary Librarian until ill-health forced him to resign late last year.

FINANCE

The Society's annual accounts for 1980 show a deficit on the year's operations of $2900.

In the coming year we will suffer from the effective withdrawal of the Commonwealth Book Bounty, but will gain from Mrs. Proctor's very generous decision to work with us in an honorary capacity.

Council is grateful to the New South Wales Government for its grants through the Division of Cultural Activities of the Premier's Department.

SCIENCE CENTRE

The activities of the Science Centre continue to improve, but the financial situation remains grave. Establishment of the "Science Centre Foundation" is now very close indeed, but arrangements for fund-raising have been unsuccessful to date. New initiatives in this direction are now under way.

On a more positive note, the Centre is now fully let, and some rents will be raised in the near future to increase income. Utilization of the Auditorium and other rooms continues to increase.

ACKNOWLEDGEMENTS

Mrs. Judith Day and Mrs. Grace Proctor have again given excellent service to the Society throughout the year. The special arrangements necessary for the Governor-General's attendance at the Dinner were especially time-consuming for Mrs. Day.

Council also records its appreciation of all those people who contributed to the success of our various activities, especially to Professor G.S. Govett, Mr. K.G. Mosher and others who assisted with the Summer School.

ANNUAL REPORT OF THE NEW ENGLAND BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

OFFICERS

Chairman: S.C. Haydon
Secretary/Treasurer: T. O'Shea
Committee: R.L. Stanton, N.H. Fletcher, R.D.H. Fayle
Representative on Council: S.C. Haydon

MEETINGS

The following meetings were held:

| | |
|---|---|
| 30 April, 1980 | "Polymers, Plastics and Fibres. The Old and the New." Assoc. Professor D.H. Napper, Dept. of Physical Chemistry, University of Sydney. |
| 10 September | "Is the standard of Science in India Comparable to that in the West?" Professor Sakuntala, Benares Hindu University. |

FINANCIAL STATEMENT

| | | |
|---|---|---|
| Balance as at 27 December, 1979 | $349.61 | |
| Credit - Interest to 30 June, 1980 | 6.85 | |
| Interest to 31 December, 1980 | 7.54 | |
| Cheque from Council | 100.00 | |
| | | $464.00 |
| Debit - Accommodation (Professor Napper) | 24.30 | |
| | | 439.70 |
| Balance at December 31st, 1980 | | $439.70 |

ABSTRACT OF PROCEEDINGS 1980 - 81

The Annual General Meeting and eight General Monthly Meetings were held in the Science Centre. Abstracts of the proceedings of these meetings are given below. In addition the Liversidge Research Lecture was delivered by Dr. S. Johns on 19th June 1980 at Macquarie University.

APRIL 2nd

113rd Annual General Meeting. Location: the Auditorium 1st Floor, Science Centre. The President, Associate Professor D.H. Napper, was in the Chair and 33 members and visitors were present.

The Annual Report of Council and the Annual Statement of Accounts were adopted. 3 new members were elected. 4 papers were read by title only.

The Clarke Medal was awarded to Dr. L.A.S. Johnson; the Edgeworth David Medal to Associate Professor G.C. Goodwin; the Society's Medal to Dr. A.A. Day; and the Archibald D. Olle Prize to Dr. R.J. Korsch.

Messrs. Wylie and Puttock, Chartered Accountants, were elected Auditors.

The Presidential Address "Polymers, Plastics and Fibres: The Old and the New" was delivered by Associate Professor D.H. Napper.

The incoming President, Dr. G.S. Gibbons, was installed and introduced to members.

MAY 7th

923rd General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 25 members and guests were present. 8 new members were elected. 2 papers were read by by title only.

An address "Good Nutrition - Whose Responsiblity? was given by Miss J.R. Rogers, Chief Dietitian, Royal Prince Alfred Hospital.

JUNE 4th

924th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 38 members and guests were present. 1 new member was elected.

An address "Centrepoint - Evolution of an Engineered Structure" was delivered by Mr. A. Wargon, Director, Wargon, Chapman and Associates, Consulting Engineers.

JULY 2nd

925th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 37 members and guests were present. 1 paper was read by title only.

An address "Dynamics and Variability of Australian Beaches" was given by Associate Professor L.D. Wright, of the Coastal Studies Unit, Department of Geography, Sydney University.

AUGUST 6th

926th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 32 members and visitors were present.

An address entitled "Porphyria - a Royal Malady" was delivered by Dr. V.K. Whittaker, Department of Biochemistry, University of Sydney.

SEPTEMBER 3rd

927th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 32 members and visitors were present. 1 new member was elected. 3 papers were read by title only.

An address "Historical Archaeology in Australia Past and Present" was given by Dr. J.M. Birmingham of the Department of Archaeology, University of Sydney.

OCTOBER 1st

928th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 44 members and visitors were present.

An address entitled "The Historical Landscapes of the New South Wales Country Town" was given by Dr. D.N. Jeans, Department of Geography, University of Sydney.

NOVEMBER 5th

929th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 44 members and visitors were present. One new member was elected.

A symposium was held with the theme "Alternative Sources of Energy". The panel of speakers comprised Mr. G.A. Lloyd, Deputy General Manager, South Pacific Petroleum NL; Dr. D.J. McCann, Director, APACE Research Centre, Millthorpe, N.S.W.; and Dr. R. Gammon, Director, Energy Centres, Energy Authority of N.S.W.

DECEMBER 3rd

930th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Dr. G.S. Gibbons, was in the Chair and 40 members and visitors were present. 1 new member was elected.

An address entitled "The Terminal Role of Lake Eyre and Australian Inland Waters" was given by Dr. John Dulhunty of the Department of Geology and Geophysics, University of Sydney.

## CITATIONS

### EDGEWORTH DAVID MEDAL

Dr. Michael Anthony Etheridge is awarded the Edgeworth David Medal for 1980 for his work in structural geology. He has made major contributions to our understanding of the development of cleavages in deformed rocks, of mechanisms of recrystallization and of the relationship between grain size and stress during crystallization.

After graduating with first class honours in geology from the University of Sydney in 1967, Dr. Etheridge obtained his Ph.D. from the Australian National University in 1971. He was a Lecturer in geology at the University of Adelaide from 1971 to 1974, and is now Senior Lecturer in the Department of Earth Sciences at Monash University. A significant proportion of his research time at Monash University has been devoted to the establishment of an experimental deformation laboratory and a transmission electron microscope facility.

Dr. Etheridge is well known for his work and is widely respected throughout the world. In the past four years he has been invited to give papers at conferences in Leiden, Barcelona, Gottingen, Palm Springs and New York. His reputation has attracted quite a large degree of support from research grant organizations including the U.S. Geological Survey, the Australian Research Grants Committee, the Broken Hill Mining Managers' Association and Mobil Exploration.

Michael Etheridge is an outstanding research worker whose distinguished contributions towards the advancement of Australian geological science have been widely acknowledged internationally and within Australia.

### THE JAMES COOK MEDAL

The James Cook Medal for outstanding contributions to Science and Human Welfare in and for the Southern Hemisphere is awarded this year to Professor Robert J. Walsh AO, OBE, FAA.

Professor Walsh was for twenty years in the immediate post World War II period the Director of the New South Wales Red Cross Blood Transfusion Service. One of the major contributions to the health of this State at that time was the setting up of a sophisticated and safe blood transfusion service. The genetics of blood groups were always close to the interests of this investigative haematologist and accordingly in 1962 he was appointed Professor of Human Genetics at the University of New South Wales. In 1973 he became the Medical Faculty's second Dean, a post which he continues to hold at present.

His service to the community has taken many forms; for example he has been an active member of numerous committees concerned with the quality of our environment. Two particular aspects of this work have been his Chairmanships of the Australian Ionizing Radiation Advisory Committee and of the Joint Commonwealth-Queensland Crown of Thorns Starfish Enquiry in 1970.

For his contributions to the practice and theory of blood transfusions and his work for the improvement of the environment, Professor Walsh is indeed a worthy recipient of the James Cook Medal.

### THE SOCIETY'S MEDAL

Maren Krysko v. Tryst came to Australia in 1949 as a refugee from Europe. She has worked as a nurse, and later was employed by the South Australian Department of Mines, and then by the C.S.I.R.O. Radio Physics Laboratory in Sydney as a photographer.

Mrs. Krysko studied at the Faculty of Mining and Metallurgy of the Technisher Universitat, Berlin - these studies, interrupted by the 1939-45 War, were later completed in Australia at the University of N.S.W., where she became the first woman post-graduate in the School of Mining Engineering.

Currently, Mrs. Krysko is employed by the School of Applied Geology, University of New South Wales, as a Senior Tutor and has lectured to mining engineers. Additionally, she has run part-time courses in minerals and related topics for the Department of Adult Education, Sydney University.

For over 8 years Maren has been active in affairs concerning underprivileged children from Western Sydney Region and has thus continued earlier interests gained when she worked in Europe with the United Nations.

Maren Krysko became a member of the Royal Society of N.S.W. in 1959, and served for a number of years as Secretary to the Society's Section of Geology. She has been a member of Council for the last 15 years, being on the executive as Honorary Editorial Secretary since 1968, also she was largely

CITATIONS

responsible for editing the Society's Centenary Volume, "A Century of Scientific Progress".

Maren has been involved with the organising and running of four Summer Schools, two being in Medicine and two being in Geology.

Always being a willing helper Maren has had the interests of the Royal Society of N.S.W. uppermost in her considerations, and on occasions has been (in a voluntary capacity) virtually responsible for the day to day running of the Society's affairs, particularly when Miss Ogle was forced through illness to leave her position as assistant secretary.

Maren Krysko v. Tryst is indeed a worthy recipient of the Society's Medal.

## THE WALTER BURFITT PRIZE AND MEDAL

The Walter Burfitt Prize, consisting of a Medal and prize money, is awarded at intervals of three years to the worker in pure or applied science, resident in Australia or New Zealand, whose papers and other contributions published during the past six years are deemed of the highest scientific merit, account being taken only of investigations described for the first time, and carried out by the author mainly in these countries.

The Prize for 1980 has been awarded to Professor Hans Adolph Buchdahl, B.Sc., A.R.C.S., D.Sc. (London), F.A.A.

Professor Buchdahl has held the Chair of Theoretical Physics at Australian National University since 1962. He previously held senior positions at Princeton and Rochester Universities in the U.S.A. and at the University of Tasmania.

He has published on a wide variety of subjects ranging from field theory to geometrical optics to statistical thermodynamics, and has successfully attacked many purely mathematical problems in the process.

The precision of his mathematics is interesting to compare with his approach in a book of his lectures, where he proceeds in a way which he says "may seem idiosyncratic at first sight, even heretical, to the extent that I have allowed physical intuition to take precedence over mathematical niceties ....."

I think that this demonstrates very clearly that Professor Buchdahl is a man who knows very precisely what he is doing: precisely the relationship between his mathematical equations and the real world.

# OBITUARIES

## WALTER HANS GEORGE POGGENDORFF

Walter Hans George Poggendorff, a member of the Royal Society of New South Wales since 1949, a member of its Council since 1957 and Honorary Librarian from 1968 to 1980, died on 7th February 1981, at the age of 77 after about 6 months' illness.

Mr. Poggendorff, remembered for his notable contribution to Australian plant breeding, became interested in agriculture from a very early age. After attending Hurlstone Agricultural High School and Hawkesbury Agricultural College, he was granted in 1924 a cadetship with the N.S.W. Department of Agriculture. He spent the next four years at the University of Sydney studying under Professor R.D. Watt and Dr. W. Waterhouse. After graduating in 1928, Mr. Poggendorff joined the N.S.W. Department of Agriculture and was posted to the Yanco Experiment Farm with the specific task of breeding new rice strains. A notable result was the development of "caloro 11", a new strain which produced for many years world record yields.

In his capacity of adviser on rice production to the N.S.W. Rice Marketing Board he visited the U.S.A. and Mexico in 1935.

Mr. Poggendorff was also involved in a wide variety of other breeding projects. These included grapes, a notable achievement being the breeding of the table grape "nyora", rockmelons and various stone fruit, particularly peaches and apricots.

In 1941, owing to the outbreak of World War II, he was transferred to Head Offoce of the N.S.W. Department of Agriculture to take up the post of Special Agronomist - miscellaneous crops. In this capacity he was responsible for the crop development and production control of drugs, fibres, essential oils etc. At the same time he continued with plant breeding, especially rice, at Yanco.

Finally, in 1947, Mr. Poggendorff became Chief of the Division of Plant Industry of the N.S.W. Department of Agriculture, a position he held until his retirement in 1968.

Mr. Poggendorff was seconded to the Commonwealth and also to a private development company for work in northern Australia, Papua-New Guinea and the Solomon Islands in 1952, 1955 and 1965. He also represented Australia in 1953 at the International Rice Conference organized by FAO (Food and Agriculture Organization of the United Nations) and in 1966 participated at a meeting of the International Rice Commission of FAO in New Delhi.

He has also been active in the New South Wales Branch of the Australian Institute of Agricultural Science and served as president of the Branch in 1957.

His pioneering efforts and significant successes in the area of plant breeding, which eventually resulted in the development of a vigorous Australian rice industry were recognized by the Royal Society of New South Wales by the award of the Society's Medal in 1972.

Mr. Poggendorff lived alone in Chatswood. Apart from his participation in the Society's affairs he devoted his leisure time to various hobbies which included cabinet making and music.

E.V. Lassak

AUDITORS REPORT TO THE MEMBERS

In our opinion:

(a) the attached Balance Sheet and Income and Expenditure Account are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1980 and of the results of the Society for the year ended on at date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provision of those Rules.

WYLIE & PUTTOCK
Chartered Accountants.

By ALAN M. PUTTOCK
Registered under the Public Accountants Registration Act, 1945 as amended.

BALANCE SHEET as at 31/12/80

| | | | | |
|---|---|---|---|---|
| | RESERVES | | | |
| 7299.57 | Library Reserve (note 2(i)) | | | 7310.57 |
| 416991.00 | Resumption Reserve (note 2(ii)) | | | 416991.00 |
| 2346.30 | LIBRARY FUND (note 2(iii)) | | | 2305.57 |
| 13403.11 | TRUST FUNDS (note 4) | | | 14206.36 |
| 76357.21 | ACCUMULATED FUNDS | | | 74258.59 |
| 516397.19 | TOTAL RESERVES & FUNDS | | | 515072.09 |
| | Represented by: | | | |
| | CURRENT ASSETS | | | |
| 49.90 | Petty Cash Imprest | | 18.39 | |
| 1177.88 | Debtors for Subscriptions | 801.26 | | |
| 1177.88 | Less Provision For Doubtful Debts | 680.26 | | |
| | | | 121.00 | |
| 2723.82 | Other Debtors & Prepayments | | 2483.91 | |
| 4102.37 | Interest Bearing Deposit | | - | |
| 7878.22 | Cash at Bank | | 2840.72 | |
| 14754.31 | | | | 5464.02 |
| | Less: CURRENT LIABILITIES | | | |
| 8305.45 | Sundry Creditors & Accruals | | 4911.97 | |
| 19.37 | Life Members Subscriptions - Current Portion | | 19.37 | |
| 121.00 | Membership Subscriptions Paid in Advance | | 209.55 | |
| 1586.89 | Subcriptions to Journal Paid in Advance | | 906.00 | |
| 10032.71 | | | | 6046.89 |
| (4721.60) | NET CURRENT LIABILITIES | | | 582.87 |

| | | | |
|---|---|---|---|
| | Add: FIXED ASSETS | | |
| 7292.66 | Furniture, Office Equipment, etc.- at cost less Depreciation | 6652.66 | |
| 13600.00 | Library - 1936 Valuation | 13600.00 | |
| 10.00 | Pictures - at cost less Depreciation | 10.00 | |
| 20902.66 | | | 20262.66 |
| 15624.26 | | | 19679.79 |
| | Add: INVESTMENTS | | |
| 30980.00 | Commonwealth Bonds & Inscribed Stock | 35580.00 | |
| 40000.00 | Loans on Mortgage | 40000.00 | |
| 70980.00 | | | 75580.00 |
| | Add: ASSOCIATED CORPORATIONS (note 3) | | |
| 1.00 | Shares - at Cost | 1.00 | |
| 419994.61 | Advances & Loans - Unsecured | 419994.61 | |
| 419995.61 | | | 419995.61 |
| 516599.87 | | | 515255.40 |
| | Less: NON-CURRENT LIABILITIES | | |
| 202.68 | Life Members Subscriptions - Non-Current Portion | | 183.31 |
| 516397.19 | NET ASSETS | | 515072.09 |

G. S. GIBBONS President

A. A. DAY Honorary Treasurer

STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31 December 1980

| 1979 | | | 1980 |
|---|---|---|---|
| 791.53 | DEFICIT for year | | 2898.68 |
| 323.02 | Donations & Interest to Library Fund | | 759.33 |
| 3486.39 | Proceeds Estate Late Dr. J. F. Codrington | | - |
| 355.11 | Transfer from Library Fund | | 800.06 |
| 73307.24 | Accumulated Funds-Beginning of Year | | 76357.21 |
| 76680.23 | AVAILABLE FOR APPROPRIATION | | 75017.92 |
| 323.02 | Transfer to Library Fund | 759.33 | |
| 323.02 | | | 759.33 |
| 76357.21 | ACCUMULATED FUNDS-Current Year | | 74258.59 |

NOTES TO AND FORMING PART OF THE ACCOUNTS
for the year ended 31st December, 1980

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1980. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

| | |
|---|---|
| Furniture | 7.5% |
| Office Equipment | 15.0% |

(b) Library Fund

During the current year an amount was transfered from the Library Fund to Accumulated Funds as a contribution to the cost of printing & mailing those copies of the Journal & Proceedings involved in the exchange programme whereby the publications of other Societies are aquired for the Library. This procedure was last adopted in the 1978 year.

(c) Library Facilities

Certain donations to the Society's Library Fund have been paid to Science House Pty Limited (see also note 3) towards the cost of providing library facilities for the Society. Such payments represent donations specifically designated by the donor as being for that purpose.

2. MOVEMENTS IN PROVISIONS AND RESERVES

(i) Library Reserve

| | 1979 $ | 1980 $ |
|---|---|---|
| Balance at 1st January | 7200 | 7300 |
| Add Sale of Books | 100 | 10 |
| Balance at 31st December | $7300 | $7310 |

(ii) Resumption Reserve

| | 1979 $ | 1980 $ |
|---|---|---|
| Balance at 1st January | 416991 | 416991 |
| Less Movements | - | - |
| Balance at 31st December | $416991 | $416991 |
| Represented by: | | |
| Shares in associated corporation | 1 | 1 |
| Loans to associated corporation | 416990 | 416990 |
| | $416991 | $416991 |

(iii) Library Fund

| | 1979 $ | 1979 $ | 1980 $ | 1980 $ |
|---|---|---|---|---|
| Balance at 1st January | | 2378 | | 2346 |
| Add Donations and bank interest | | 323 | | 759 |
| | | 2701 | | 3105 |
| Less Library purchases | 355 | | 800 | |
| Library fittings & equipment | - | | - | |
| Paid re library facilities | - | | - | |
| | | 355 | | 800 |
| Balance at 31st December | | $2346 | | $2305 |
| Represented by: | | | | |
| Cash at bank | | 51 | | 760 |
| Commonwealth Bonds | | 2300 | | 2300 |
| Owing to general funds | | (5) | | (755) |
| | | $2346 | | $2305 |

NOTES TO AND FORMING PART OF THE ACCOUNTS
for the year ended 31st December, 1980

3. ASSOCIATED CORPORATIONS

The Society has entered into a joint venture with the Linnean Society for the establishment and operation of a Science Centre for New South Wales and to facilitate this, a company, Science House Pty. Limited, has been formed in which each Society has 50% interest.
Advances and loans to the company have been on an interest free basis repayable at call. No material repayments are anticipated prior to 31st December, 1981

| | 1979 $ | 1980 $ |
|---|---|---|
| Balance at 1st January, | 419995 | 419995 |
| Less Movements | - | - |
| Balance at 31st December | $419995 | $419995 |
| Representing: | | |
| Resumption reserve | 416991 | 416991 |
| Accumulated funds | 3004 | 3004 |
| | $419995 | $419995 |

4. TRUST FUNDS

| | 1979 $ | Clarke Memorial $ | Walter Burfitt Prize $ |
|---|---|---|---|
| **Capital** | | | |
| Balance at 1st January | 11100 | 4800 | 3000 |
| Capitalisation of accumulated revenue | - | - | - |
| Balance at 31st December | $11100 | $4800 | $3000 |
| **Revenue** | | | |
| Revenue income for period | 1378 | 517 | 323 |
| Less Expenditure | 888 | 46 | 36 |
| | 490 | 471 | 287 |
| Add Balance from 1979 | 1813 | 702 | 792 |
| | 2303 | 1173 | 1079 |
| Less Capitalisation | - | - | - |
| Total Revenue | $2303 | $1173 | $1079 |
| Total Trust Funds | $13403 | $5973 | $4079 |

| | Liversidge Bequest $ | Olle Bequest $ | Total $ |
|---|---|---|---|
| **Capital** | | | |
| Balance at 1st January | 2000 | 1300 | 11100 |
| Capitalisation of accumulated revenue | - | - | - |
| Balance at 31st December | $2000 | $1300 | $11100 |
| **Revenue** | | | |
| Revenue income for period | 215 | 273 | 1328 |
| Less Expenditure | 337 | 105 | 524 |
| | (122) | 168 | 804 |
| Add Balance from 1979 | 109 | 700 | 2303 |
| | (13) | 868 | 3107 |
| Less Capitalisation | - | - | - |
| Total Revenue | $(13) | $868 | $3107 |
| Total Trust Funds | $1987 | $2168 | $14207 |

THE ROYAL SOCIETY OF NEW SOUTH WALES

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31 December 1980

| 1979 | | | | 1980 |
|---|---|---|---|---|
| | INCOME | | | |
| | Membership Subscriptions - | | | |
| 7252.00 | Ordinary | | | 7130.90 |
| | Membership Subscriptions - | | | |
| 19.37 | Life Members | | | 19.37 |
| 105.60 | Application Fees | | | 54.00 |
| 7376.97 | | | | 7204.27 |
| 3356.29 | Subscriptions to Journal | | | 3186.59 |
| 2000.00 | Government Subsidy | | | 1500.00 |
| | Donations - Printing Journal & | | | |
| - | Publications | | | 43.21 |
| | Total Membership & Journal | | | |
| 12733.26 | Income | | | 11934.07 |
| 6678.40 | Interest Received | | | 7377.59 |
| - | Sale of Reprints | | | 154.35 |
| 66.50 | Sale of Back Numbers | | | 179.60 |
| 84.00 | Sale of Other Publications | | | 34.00 |
| 3.00 | Donations - General | | | - |
| - | Annual Social Surplus | | | 51.74 |
| 559.40 | Summer School Surplus | | | 302.50 |
| 320.57 | Other Income | | | 136.52 |
| 20445.13 | | | | 20170.36 |
| | Less:EXPENSES | | | |
| 726.00 | Accountancy Fees | | 867.00 | |
| 33.00 | Advertising | | - | |
| 22.75 | Annual Social | | - | |
| 374.00 | Audit Fees | | 443.00 | |
| 100.00 | Branches of the Society | | 22.36 | |
| 132.50 | Cleaning | | 149.00 | |
| 855.00 | Depreciation | | 640.00 | |
| 254.64 | Electric Light & Power | | 282.90 | |
| 224.29 | Entertainment Expenses | | 66.80 | |
| 531.16 | Insurance | | 589.16 | |
| | Journal Publication Costs | | | |
| | Printing - Current Year | | | |
| 3941.46 | Volume | 4983.00 | | |
| 714.58 | Wrapping & Postage | 1158.40 | | |
| | | | 6141.40 | |
| - | Legal Costs | | 241.20 | |
| 364.94 | Library Purchases | | 50.06 | |
| 81.95 | Miscellaneous Expenses | | 49.28 | |
| 825.45 | Monthly Meeting Expenses | | 892.45 | |
| | Newsletter Printing & | | | |
| 1214.62 | Distribution | | 1603.27 | |
| 304.70 | Postage | | 266.96 | |
| | Printing & Stationery - | | | |
| 160.27 | General | | 301.50 | |
| 609.66 | Provision for Doubtful Debts | | 308.38 | |
| 2781.28 | Rent | | 2781.28 | |
| 168.50 | Repairs & Maintenance | | - | |
| 185.90 | Reprints - Loss on Sale | | - | |
| 6314.94 | Salaries | | 7140.04 | |
| 77.95 | Secretarial Services | | 13.88 | |
| 237.12 | Telephone | | 219.12 | |
| 21236.66 | | | | 23069.04 |
| 791.53 | DEFICIT for the year | | | 2898.68 |

FUNDS STATEMENT FOR THE YEAR ENDED 31ST DECEMBER 1980

| | 1979 $ | 1979 $ | 1980 $ | 1980 $ |
|---|---|---|---|---|
| SOURCE OF FUNDS | | | | |
| Operating deficit for the year | (791) | | - | |
| Add: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | 855 | | - | |
| Provision for doubtful debts | 610 | | - | |
| Funds derived from operations | | 674 | | - |
| Donations and interest to library fund | | 323 | | 759 |
| Library sales | | 100 | | 10 |
| Trust fund income | | 1378 | | 1328 |
| Reduction in working funds | | - | | 4998 |
| Life membership subscriptions | | 80 | | - |
| Proceeds Estate Late Dr. J. F. Codrington | | 3486 | | - |
| | | $6041 | | $7095 |
| APPLICATION OF FUNDS | | | | |
| Operating deficit for the year | - | | 2899 | |
| Less: | | | | |
| Items not involving the outlay of funds in the current period: | | | | |
| Depreciation of fixed assets | - | | (640) | |
| Provision for doubtful debts | - | | (308) | |
| Funds applied to operations | | - | | 1951 |
| Reclassification of life members subscriptions in advance | | 25 | | 20 |
| Increase in investments | | 3400 | | 4600 |
| Trust fund expenses | | 888 | | 524 |
| Increase in working funds | | 1728 | | - |
| | | $6041 | | $7095 |

# JOURNAL AND PROCEEDINGS
# OF THE
# ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 113

PART 1-4

1980

ISSN 0035-9173

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SCIENCE CENTRE, 35 CLARENCE STREET, SYDNEY

# Royal Society of New South Wales

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## Part 3



## Part 4



**Dates of publication:**
**Parts 1 and 2: 25th June, 1980**
**Parts 3 and 4: 13th April, 1981**

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Aanuscripts should be addressed to the Honorary retary (address given above).

Aanuscripts submitted by a non-member must be comnicated by a member of the Society.

ach manuscript will be scrutinised by the Publications nmittee before being sent to an independent referee who advise the Council of the Society on the acceptability of paper. In the event of rejection, manuscripts may be sent wo other referees.

apers, other than those specially invited by Council, will / be considered if the content is substantially new erial which has not been published previously, has not 1 submitted concurrently elsewhere, nor is likely to be lished substantially in the same form elsewhere. Wellwn work and experimental procedure should be referred nly briefly, and extensive reviews and historical surveys ıld, as a rule, be avoided. Letters to the Editor and short :s may also be submitted for publication.

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ffset printing with "Typeset-it-Yourself" preparation of aster manuscript suitable for photography is used in the duction of the Journal. Authors will be supplied with a of special format paper. An IBM Selectric (Golf Ball) writer with ADJUTANT 12 typeface must be used. ogical and reference material are shown in *Light Italic*. ıbol 12 has most type required for mathematical ressions and formulae. Detailed instructions for the st are included in the Style Guide.

ESENTATION OF INITIAL MANUSCRIPT R REVIEW

ypescripts should be submitted on heavy bond A4 paper. econd copy of both text and illustrations is required for e use. This may be a clear carbon or photographic copy. ıuscripts, including the abstract, captions for illusons and tables, acknowledgments and references should yped in double spacing on one side of the paper only.

lanuscripts should be arranged in the following order: ; name(s) of author(s); abstract; introduction; main text; clusions and/or summary; acknowledgments; rences; appendices; name of Institution/Organisation re work carried out/or private address as applicable; manuscript received by the Society. A table of contents ıld also accompany the paper for the guidance of the or.

pelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the Australian Code of Stratigraphic Nomenclature (revised fourth edition) and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra. The letter of approval should be submitted with the manuscript.

*Abstract.* A brief but fully informative abstract must be provided.

*Tables* should be adjusted for size to fit the format paper of the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

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*Note:* There is a reduction of 30% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. the scale of maps or diagrams must be given in bar form.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper (no negative is required).

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*References* are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow the preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by author and then chronologically by date.

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## VOLUME 114, PART 1



## VOLUME 114, PART 2



Publicity Press (NSW), 66 O'Riordan St, Alexandria, Sydney.

# Journal and Proceedings of the Royal Society of New South Wales

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# THE ROYAL SOCIETY OF NEW SOUTH WALES



Address:— Royal Society of New South Wales,
35 Clarence Street,
Sydney, NSW, 2000,
Australia.
Tel: Sydney 29 1496

## THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library; awards of Prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special Meetings are held for the Pollock Memorial Lecture in Physics and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology.

Membership is open to any interested person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personnally known. Membership categories are: Ordinary Members, Absentee Members and Associate Members. Annual Membership fee may be ascertained from the Society's Office.

Subscriptions to the Journal are welcomed. The current subscription rate may be ascertained from the Society's Office.

The Society welcomes manuscripts of research (and occasional review articles) in all branches of science, art, literature and philosophy, for publication in the Journal and Proceedings.

Manuscripts will be accepted from both members and non-members, though those from the latter should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the above address.

# JOURNAL AND PROCEEDINGS
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# ROYAL SOCIETY OF NEW SOUTH WALES

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ISSN 0035-9173

# Galaxies, Clusters and Invisible Mass*

EDWIN E. SALPETER

## INTRODUCTION

I am happy to be associated with the James Pollock Memorial Lectures, especially since they provide a tie with my formative years at Sydney University: My last year as a student here, 1945, was about when these lectureships were started. The topic of my talk also provides a link - theoretical physics and radioscience made the strongest impression on me as a Sydney student and these two topics are interwoven in the subject of my talk.

Since a memorial lecture should appeal to a fairly broad audience, I usually like starting off qualitatively and getting mathematical only towards the end. However, in the present case, I have to start off with an equation, Kepler's Law, even before I state the topic: For a circular orbit at a distance r from the centre of a mass M(r) the rotation velocity is given by

$$V^2_{rot} = \frac{GM(r)}{r} \qquad (1)$$

A recurring theme of my talk is the use of observed velocities V of "test particles" to infer the total (gravitational) mass M of a system, whether "invisible" or not. The first topic (Rotation Curves of Spiral Galaxies) will be the rotation curve of a spiral galaxy, where orbits are fairly accurately circular and the gravitational mass inside radius r is given almost directly by equation (1). However, I will touch on various other topics which, at first sight, sound like a different phenomenon and yet the governing equation is essentially (to within a factor of two) the same:

For an equilibrated gravitationally bound system of N particles, the Virial Theorem can be used, which is essentially the "statistical average" equivalent of equation (1). At least for the *core* of a rich cluster of galaxies the Virial Theorem works quite well; for the outer layers of a galaxy cluster I will describe (Dynamical Masses for Galaxy Clusters) more intricate dynamical calculations, but they are merely a quantitative refinement to the Virial Theorem. For the formation of a galaxy cluster out of a local density enhancement in an expanding cosmological model an important question is whether the proto-cluster is gravitationally bound or not. This question can be rephrased by asking whether the initial expansion velocity was less than $V_{esc}$ or not, where

$$V_{esc} = \left(2\frac{GM}{r}\right)^{\frac{1}{2}} \qquad (2)$$

is the escape velocity at a distance r from mass M (which differs from equation (1) by merely a factor of 2). Finally, for cosmological models an important question is whether the universe is open or closed. This is usually expressed by asking whether the mean density of the universe is smaller or larger than the cosmological "critical density".

$$\rho_{crit} \equiv (3/8\pi G)H_0^2 \sim 10^{-29} \mathrm{gm\ cm}^{-3} \qquad (3)$$

where $H_0$ is the Hubble constant. However, this critical density is essentially that required to make the "mass of the universe" such that $V_{esc}$ in equation (2) equals the speed of light c.

Instead of giving masses or mass densities in absolute terms, it will be more convenient to give mass-to-light ratios (expressed in units of $M_0/L_0$ where $M_0$ is solar mass and $L_0$ is solar luminosity). For many considerations, the numerical value of $H_0$ is unimportant, but I will use a value of 70 kms$^{-1}$ Mpc$^{-1}$ (as a compromise between two "fashionable" values of $\sim$50 and $\sim$100). The dimensionless cosmological density parameter $\Omega$ can be re-expressed as

$$\Omega \equiv \frac{\langle\rho\rangle}{\rho_{crit}} \sim \frac{\langle M/L\rangle}{1500} \qquad (4)$$

where $\langle\rho\rangle$ is the mean density of the universe (averaged over volumes large compared with our Local Supercluster of galaxies). To give a preview of Sections II and III: Ordinary stars give an average mass-to-light ratio of M/L $\sim$5 or 10, whereas rotation curves for galaxies and velocity dispersions in galaxy clusters give larger value - hence the inference of "invisible mass" somewhere.

## ROTATION CURVES OF SPIRAL GALAXIES

Optical measurements of shifts in spectral lines from stellar distributions in nearby spiral galaxies can give, at least in principle, the velocity (component along the line of sight) as a function of distance r from the galaxy centre. Equation (1) then gives M(r), the total mass contained inside a sphere of radius r, if the mass distribution is spherical; if the mass is distributed in a disk the numerical factor in the equation only changes by $\pi/2$ with even smaller changes for other distributions. Such mass determinations were already carried out more than 50 years ago (Öpik, 1922) and much optical data exists on rotation curves $V_{rot}(r)$ for the *inner* galactic disks of spiral galaxies (Burbidge and Burbidge, 1975). Since the mass density is finite at the centre, $M(r) \propto r^3$

* *The J.S. Pollock Memorial Lecture, delivered before the Royal Society of New South Wales, 30th July, 1981.*

at small radii r and $V_{rot}(r)$ increases linearly at first. Since the mass density decreases outwards the linear increase in $V_{rot}(r)$ stops soon, but the behaviour at large r is of greatest interest. The optical surface brightness $\sigma_{opt}(r)$ decreases exponentially with r (Freeman, 1970) and so would the mass surface density $\sigma_M(r)$ *IF* most mass were contributed by ordinary stars, so that the mass to light ratio M/L were constant everywhere. In that case, M(r) would approach the total mass $M_{tot}$ rapidly and the rotation curve would approach the Kepler Law, $V_{rot} \propto r^{-\frac{1}{2}}$, in the outer regions.

Because of the exponential decrease of optical surface brightness it is difficult to extend optical rotation curves to the outer regions, but fortunately the neutral hydrogen in the galactic disk extends about 2 or 3 times further out than most of the starlight. The direct contribution to $M_{tot}$ of the hydrogen gas is very small, but modern radiotelescopes are very sensitive and can detect neutral hydrogen and measure its velocity (or, rather, its component along the line of sight) through the λ21cm hyperfine structure line. By a peculiar quirk of history, one of the earliest galaxies for which accurate 21cm data were taken, M81, showed the expected turnover in the rotation curve and the approach to the Kepler Law and seemed to corroborate the assumption of a constant mass to light ratio. Troubles with this assumption soon surfaced, in particular our nearest large galaxy, M31 (Andromeda), seemed to show a flat rotation curve. A trigonometric conversion factor has to be applied to the measured line-of-sight velocity component to derive $V_{rot}(r)$ and there could be uncertainties if the outer disk of the galaxy is warped. Fortunately, these uncertainties are quite unimportant when the galaxy is viewed almost edge-on. The most recent 21cm radiotelescopes are sensitive enough to be able to observe a large number of galaxies and one can select those which are close to edge-on. The Westerbork array (Sancisi, 1976) has particularly good angular resolution and the Arecibo dish (Krumm and Salpeter, 1979) has particularly good sensitivity and a lot of reliable data is now available (including also newer optical data). The situation has been reviewed by Bosma and van der Kruit (1979) and by Rubin (1979) and it is now clear that most spiral galaxies (with a quarter or less of the galaxies, including M81, forming an exception) have flat rotation curves and M(r) must increase linearly with r - at least as far as the observations can be carried out.

The 21cm observations peter out at two or three times the optical radius of a typical galaxy, because the hydrogen signal becomes too weak, and the rotation curves are usually still flat there. The last values for M(r) provide lower limits for $M_{tot}$ and are two or three times larger than the old optical estimates, giving a lower limit to the overall mass to light ratio of about $20M_\odot/L_\odot$. This is not spectacular in itself, but the *local* mass to light ratios are: The mass surface density decreases only as $r^{-1}$ whereas the optical surface brightness decreases exponentially, so that $\sigma_M(r)/\sigma_L(r)$ increases very drastically, as shown in Figure 1, up to about $500M_\odot/L_\odot$. We therefore have the tantalizing situation of knowing about the existence of "almost invisible" matter but not knowing how much further out it extends and how much larger $M_{tot}$ is than our lower limit for it.

We also do not know in what physical form the matter in such an "invisible galaxy halo" is. Some form of stars seems the most conservative hypothesis, but "ordinary stars" in the mass range $0.2M_\odot$ to $2M_\odot$ have too small values for M/L (shown in Figure 2). M/L increases as stellar mass decreases and stars of about $0.1M_\odot$ are sufficiently faint for present-day data, although they might be detectable with improved optical sensitivity; objects less massive than about $0.08M_\odot$ cannot burn hydrogen at all, cool off rapidly and these "overgrown Jupiters" are essentially invisible. By analogy with the well-studied "stellar population II halo", it is usually assumed that a "stellar population III" was formed *before* stellar populations I and II, more than $10^{10}$ years ago. If that is true, a population of very massive stars - initially - is also a possibility ($\geq 4M_\odot$, say), since they will have ended their main sequence life a long time ago and their compact remnants (white dwarfs, neutron stars or black holes) are very faint optically (Salpeter, 1977).

Before we can say if it is reasonable that the masses of the earliest stars to form were either very small or very large, we should look at the situation of "ordinary" stars. For this purpose one should look not at the present-day observed luminosity function, but the extrapolation back to the birthrate or "initial mass function IMF" (I am again happy to talk on this topic in this continent since my first work in "real" astronomy was done in Australia on this subject). This IMF, when expressed in the appropriate logarithmic form as shown schematically in Figure 2, is still slightly uncertain (Salpeter, 1955; Lequeux, 1979; Miller and Scalo, 1979), but the interesting thing is that it is rather flat. A similar empirical fact holds in a more sociological realm - roughly as many people live in cities between 1 and 2 million population as in towns between 10,000 and 20,000 population, etc. ... The causes are not really understood in either realm, but it is known that the demographic law sometimes fails such as in the megalopolis on the Eastern U.S. seabord or in highly rural populations. We should perhaps not be too surprised if a similar thing happened to tilt the earliest IMF towards very small or very large masses.

## DYNAMICAL MASSES FOR GALAXY CLUSTERS

We saw that we can only get a lower limit to the total gravitational mass of an individual galaxy and that there might be more "invisible" mass further out, either bound to the galaxy or elsewhere. Fortunately, an appreciable fraction of all galaxies lives in large clusters and we can investigate the total gravitational mass of such a cluster by studying the dynamics of the galaxies in it. There are different types of clusters, from loose ones containing few galaxies to very "rich" ones, containing thousands of galaxies with very high central number density. The very richest clusters show signs of relaxation subsequent to their formation due to dissipative galaxy - galaxy interaction. Fortunately, we are situated relatively close

to a medium-rich cluster, the Virgo cluster, which is large enough to give good statistics but has not suffered much relaxation, so that we can now treat individual galaxies as point particles.

As I mentioned in the Introduction, the Virial Theorem is the statistical equivalent of Kepler's Law, relating the mean-squared velocity of particles in a cluster (the systemic velocity of each galaxy relative to the cluster centre) to total gravitational mass of the cluster (divided by its radius. De Vaucouleurs (1960) already applied the Virial Theorem to velocity data for the Virgo cluster and found a surprisingly large cluster mass, corresponding to a mass-to-light ratio of about 500. Some objections have been raised to the use of the Virial Theorem, which strictly speaking applies only to an isolated system at equilibrium, to a galaxy cluster which is not fully isolated and still has galaxies falling in on it from the outside. It is important to settle this point, since it has a bearing on two interesting questions:

1. How much invisible mass is there in the Virgo cluster core?
2. What is the value of the cosmological density parameter $\Omega$?

Equation (4) relates $\Omega$ to the mean mass-to-light ratio $\langle M/L \rangle$ and one might think that questions 1. and 2. above are identical. Until a few years ago this view was prevalent and there was optimism that a reliable value for $\Omega$ would be found soon. Developments since have illustrated an unfortunate (but fascinating) aspect of observational cosmology: As more observational data becomes available on some topic, the claimed accuracy for determining some interesting number often gets *worse* for a while - not better - because some systematic cause for error has been found but not yet eliminated. We have seen that some invisible matter is associated with individual galaxies, but it is becoming more and more likely that M/L is even larger for the core of a cluster like Virgo than for an individual galaxy. We therefore have to expect the possibility that M/L either increases or decreases radically with distance from the centre of a large cluster, so that the two questions above become decoupled. We shall see that question 1. can be answered quite accurately, but question 2. is wide open.

Since the pioneering work on the Virgo cluster and its surrounding by de Vaucouleurs (much of it carried out in Australia) there have been advances both on the observational and theoretical side. Observationally there has been a veritable information explosion, both from optical spectroscopy and 21cm-line work, and accurate systemic velocities are now available for more than a thousand galaxies in the general Virgo cluster vicinity. Instead of merely getting one velocity dispersion for the whole cluster, one can get observational values for velocity dispersion as a function of angular distance $\theta$ from the Virgo cluster centre. Part of this data is shown in Figure 3 for the cluster core (nominally defined as the sphere inside $\theta \sim 6°$, where the number density of galaxies has a steep gradient) and some distance outside. The cluster is by no means isothermal, but the velocity dispersion decreases with increasing $\theta$ (it becomes almost constant again at slightly larger $\theta$). On the theoretical side the main advance has been the possibility to carry out a large series of dynamical model calculations (Peebles, 1970; Gott, 1975; Gunn, 1977; Silk and Wilson, 1979; Hoffman, Olson and Salpeter, 1980), which can eliminate the controversy surrounding the (much simpler) use of the Virial Theorem.

Although the supercluster surrounding the Virgo cluster is flattened, the cluster itself is not, so that spherically symmetric dynamical models are sufficiently accurate. Figure 4 is a schematic illustration of such a model for an open universe which already contained one spherically symmetric density enhancement at early times. Because of the enhanced gravitational force, the total energy per particle is negative for all spherical shells inside "marginally bound surface" containing mass $m^*$. At early times all shells take part in the general cosmological expansion but at some epoch (labelled as time $t = 1$) shells far inside of $m^*$ come to rest, start collapsing and hit the origin at approximately $t = 2$. Shells further out (but still inside $m^*$) reach zero velocity at later times and, whatever the present epoch $t_{now}$ is, there exists some zero velocity surface. At any finite time the cluster is never fully isolated from its surrounding, but at times later than about $t \sim 3$, there is a substantial cluster core which does not change its internal density much although the matter outside $m^*$ keeps expanding and decreasing its density.

There are at least two dimensionless parameters characterizing a particular model - the present epoch $t_{now}$ (relative to the first turnaround of the proto-cluster), and the present value of the cosmological density parameter $\Omega$. A scaling factor can be adjusted to make the overall mean velocity dispersion of the model agree with the observed mean, but there is still the question whether the shape of the curve for velocity dispersion as a function of distance $\theta$ from the cluster centre fits the observed curve (the histogram) in Figure 3. A number of curves for different models are also shown in Figure 3 and they do in fact fit the observed shape quite well. That is gratifying from one point of view - the basic assumptions (growth of an original approximately spherical density enhancement, neglect of dissipation, etc.) cannot be badly off - but disappointing from another: these curves (taken from Hoffman, Olson and Salpeter, 1980) cover a range of $\Omega$ from 0.03 to 0.7 (and we now have models covering an even wider range) and since they all fit equally well, one of the questions I asked above has a negative answer - if the mass-to-light ratio is allowed to vary with distance from the centre (or with density) but if we do not know the sign of the variation then we can say nothing at the moment about the cosmological density parameter $\Omega$!

The other question, however, has a very positive answer: all the models which fit the observed velocity dispersion curve give almost the same mass and mass-to-light ratio for a sphere of radius which subtends an angle of 6°. We get

$$M/L \sim 500 M_0/L_0$$

and $M_{6^\circ} \simeq (3.8 \pm 0.4) \times 10^{12} M_\odot$

if we assume $H_0 \simeq 70 kms^{-1} Mpc^{-1}$ (in fact the largest uncertainty in $M_{6^\circ}$ at the moment is due to the uncertainty in the Hubble constant $H_0$). Since $\Omega$ varies from model to model, M/L for much larger volumes than the 6°-sphere is uncertain (and the same is true to a lesser extent for much smaller volumes) but for the volume picked by optical astronomers as "the Virgo cluster proper" the Virial Theorem is vindicated pretty well. The most important result, though, is the fact that M/L is at least 20 times larger still than we obtained for individual galaxies (out to where the neutral hydrogen begins to peter out) so that we have striking evidence for even more invisible mass - possible of a different form and probably distributed differently: if the invisible mass is mainly low-mass stars from large proto-haloes they are likely to have been "rubbed off" in the dense cluster core more than further out and M/L decreases with increasing distance from the cluster centre; if the invisible mass is due mainly to massive neutrinos forming the background cluster (Sato and Takara, 1980), the neutrinos will have suffered even less dissipation than proto-galaxies, have a larger cluster radius and M/L increases.

## SUPERCLUSTERS AND FUTURE WORK

I almost ended by saying that we know the mass of a cluster core, such as the inner 6° of the Virgo cluster, quite well but know nothing about the mean mass-density (or the dimensionless parameter $\Omega$): the masses of the cluster cores alone would give only $\Omega \sim 0.02$, a constant mass-to-light ratio M/L everywhere would give $\Omega \sim 0.3$, but an increased M/L outside of cluster cores could easily give a closed universe, $\Omega \geq 1$. There is some hope to get more information in the future from the study of "superclusters", which come either in the form of tenuous surroundings of a single cluster core of about 10 or 20 times its radius (which is the case for the Local Supercluster which surrounds the Virgo cluster), or as a collection of 4 or 5 clusters (de Vaucouleurs, 1956; Jôeveer, Einasto and Tago, 1978).

The attempts made at the moment for getting some measure of the mass of the Local Supercluster mainly centre around measuring the "Virgocentric deviation velocity $\Delta V$ from pure Hubble flow". By this is meant the additional recession velocity (above the observed one) we would have relative to the Virgo cluster if we had not been decelerated by the gravitational pull of the Virgo cluster. This requires precision measurements of the relative distances from us to galaxies in different directions, which is a difficult task at the moment. Consequently, present estimates for $\Delta V$ cover a rather wide range from about 125 to 500 km/sec, but hopefully the accuracy will improve. Unfortunately it is not clear whether even an accurate observed value for $\Delta V$ will be able to pin down $\Omega$. The reason is that $\Delta V$ does not depend so much on the total mass contained in the Local Supercluster (or in a sphere centred on the Virgo Cluster and passing through our location), but on the *excess* mass contained over what the mean cosmological density would give. We thus can have the paradoxical situation that of two models (with M/L varying differently), both giving the velocity dispersion of the cluster core correctly, the one with the *larger* $\Omega$ may predict a *smaller* $\Delta V$.

Some attempts have also started to measure velocities equivalent to $\Delta V$ in a supercluster containing several clusters (Ford, et al., 1981). I am equally sceptical that these measurements can give $\Omega$ directly, but I am confident that we will learn much about the formation, structure and evolution of superclusters from such studies. From such understanding will eventually also come a value for the elusive parameter $\Omega$ and I hope there will be a more definitive Pollock Memorial Lecture on this subject before the end of the millenium.

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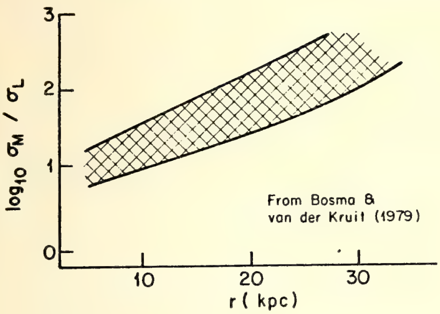


Fig. 1

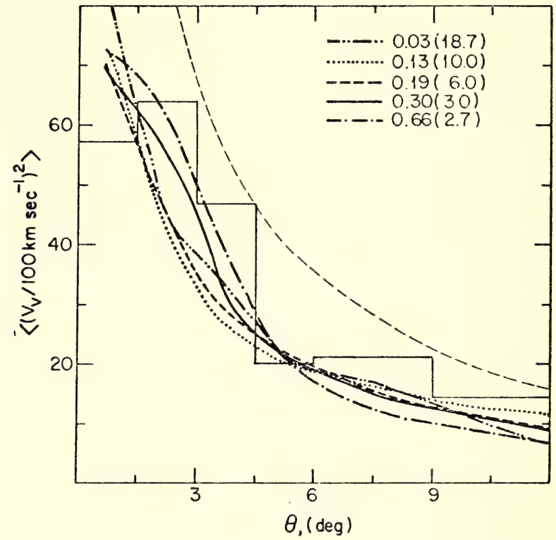


Fig. 3

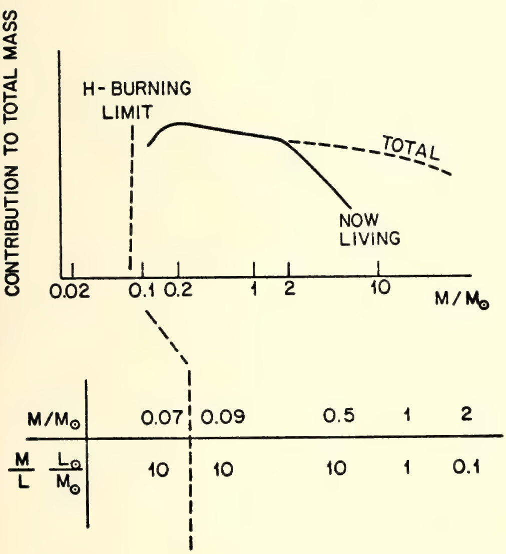


Fig. 2

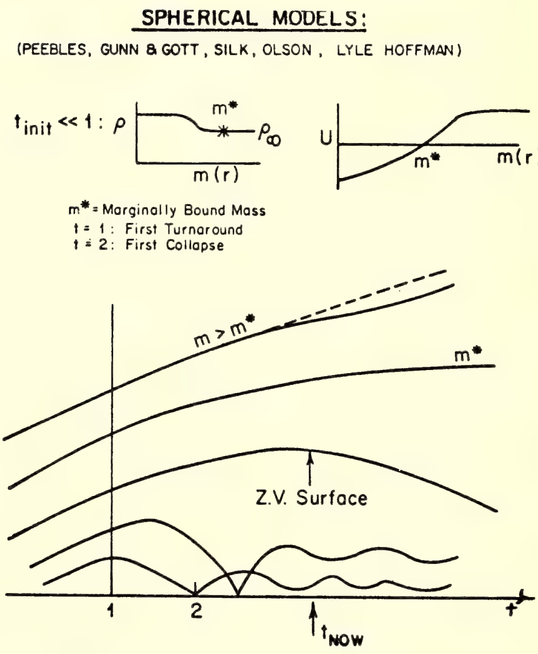


Fig. 4

Figure 1: The ratio of local surface mass density $\sigma_M$ to optical surface brightness $\sigma_L$ as a function of radial distance r from the centre of an individual galaxy.

Figure 2: A schematic picture of the "initial mass function" IMF in logarithmic units as a function of stellar mass M. Typical mass-to-light ratios are also shown.

Figure 3: The velocity dispersion of systemic galaxy velocities as a function of angular distance $\theta$ from the centre of the Virgo cluster. The histogram is the observational data, the curves are for various models (labelled by $\Omega$ and by $t_{now}$ in brackets).

Figure 4: A schematic picture for the time development of a density enhancement into a cluster.

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# *Papillatabairdia,* A New Ostracod Genus from Brisbane Water, New South Wales

CHRISTOPHER BENTLEY

ABSTRACT. A new podocopid ostracod genus, *Papillatabairdia* (Bairdiacea, Bairdiidae), is described from Brisbane Water, N.S.W., with a new species, *Papillatabairdia dentata.*

## INTRODUCTION

The marine Ostracoda of the area around Sydney were first described by Brady (1880). They were collected in Port Jackson and at Station 164a (Fig. 1) by the Challenger expedition in 1874. Until now nothing further has been published. There have been papers published on Ostracoda from elsewhere on the Australian coast, notably by McKenzie (1967) and Hartmann (1978, 1979, 1980).

The present paper deals with a new genus and species from Brisbane Water, to the north of Sydney off Broken Bay (Fig. 1). Further papers will deal with the remainder of the fauna.

The specimens, consisting entirely of carapaces and dissociated valves, were collected between March 1977 and January 1978. The drawing (Fig. 2) was made with the aid of a Leitz camera lucida. The JEOL JSM-35 scanning electron microscope at the University of New England was used for figures 3-7.

Holotype and paratypes are deposited in the Australian Museum, Sydney (catalogue numbers P30661-68). Paratypes are also deposited in the collection of the Department of Geology of the University of New England (number F16363, locality number L1821).

## SYSTEMATIC DESCRIPTION

Class OSTRACODA Latreille, 1806
Order PODOCOPIDA Müller, 1894
Suborder PODOCOPA Sars, 1866
Superfamily BAIRDIACAE Sars, 1866
Family BAIRDIIDAE Sars, 1888
Genus *PAPILLATABAIRDIA,* gen. nov.
Type Species *PAPILLATABAIRDIA DENTATA,* sp.nov.

Derivation of name: *papilla* (Latin) = nipple, and the generic name *Bairdia,* from the appearance of the ornament of the valve.

Diagnosis: Carapace small to medium; ovately subtrapezoidal in lateral view. Surface ornament papillate. Inner lamella broad anteriorly, narrower posteriorly. Marginal pore canals numerous, simple, straight. Two shallow vestibula present.

Description: As for the type species. The genus is at present monospecific.

Remarks: *Papillatabairdia,* gen. nov., can be distinguished from other members of the family Bairdiidae by its more reniform shape, its rectangular posterior and its papillate ornamentation.

*Papillatabairdia dentata* sp. nov.
(fig. 2-7)

1978 *Bythocypris* sp. HARTMANN: 73-74; Table II fig. 14-16

Derivation of name: *dentatum* (Latin) - toothed, from the appearance of the anteroventral margin of the valve in lateral view.

Holotype: P30664, a female left valve (fig. 4).

Type locality: Channel to the east of St Huberts Island, Brisbane Water.

Type stratum: Recent muddy sand.

Material: 45 specimens.

Diagnosis: A *Papillatabairdia* characterized by a dentate anterior margin, subrectangular posterior and a long sinuous dorsal scar.

Description: External: Carapace medium sized, subtrapezoidal in lateral view, anterior margin broadly downturned, ventral margin strongly indented medially; posteroventral margin broadly rounded. Posterodorsal margin gently convex; dorsal margin strongly arched, apex approximately medial. Subelliptical in dorsal view, tapered anteriorly, rounded posteriorly, laterally gently convex. Greatest height approximately medial, 1/2 length of valve. Greatest width medial, from 1/3 to 3/4 length of valve. Left valve larger than right, overlapping continuously, greatest overlap posterior.

Ornament consists of abundant papillae, most pronounced at and near anteroventral margin becoming weaker over remaining surface, especially dorsally. Normal pore canals mostly situated in papillae, occasionally between them; mostly open, type A (*sensu* Puri and Dickau, 1969).

Internal: Inner lamella broad anteriorly, narrower in posterior; long, shallow anterior and shallower posterior vestibula present. Marginal pore canals abundant, simple, straight (36 in anterior). No marginal pore canals in papillae.


Fig. 1. Locality map of central part of N.S.W. coast, showing present locality and Challenger Station 164a

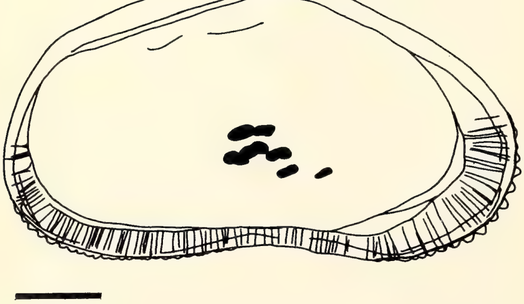
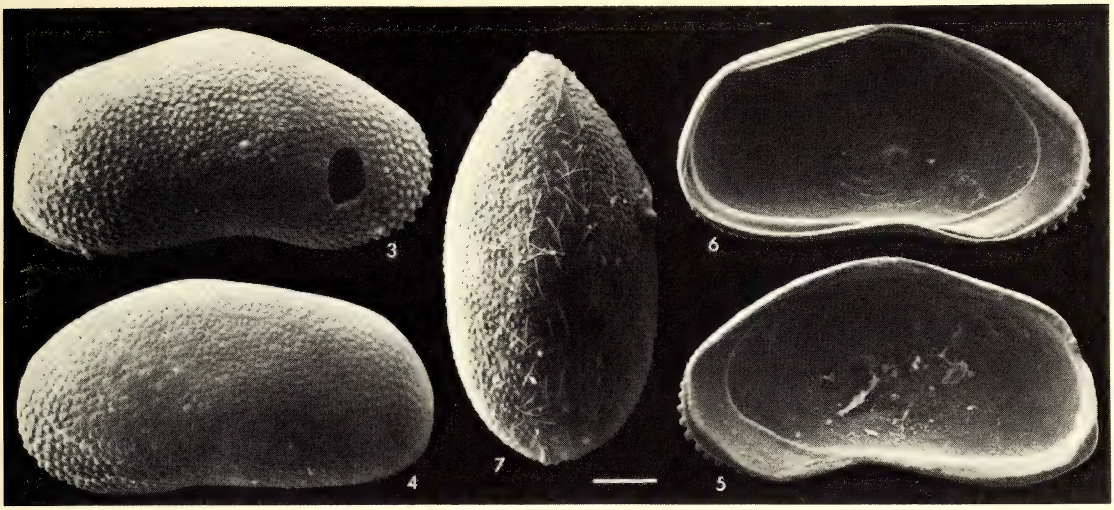


Fig. 2. *Papillatabairdia dentata* gen. et sp. nov. Adult female left valve, holotype (P30664), lateral view in transmitted light Scale bar = 100 microns




Figs. 3-7. *Papillatabairdia dentata*, gen.et. sp. nov. *3*, adult male right valve,external lateral view. *4*, juvenile left valve, paratype (P30663), external lateral view. *5*, adult male right valve, paratype (P30662), internal lateral view. *6*, adult female left valve, holotype (P30664), internal lateral view. *7*, adult female carapace, dorsal view. Specimens in Figures 3 and 7 broken during removal from SEM stub. Scale bar = 100 microns.

Hinge weak, adont, consists of bar in right valve and complementary groove in left valve. Accommodation grooves anterodorsal and posterodorsal in left valve. Small anterior stop ridge on anteroventral part of inner lamella of left valve.

Central muscle field consists of 7 ovoid or subcircular scars in 3 rows, 2 scars in dorsal row slightly posterodorsal to median row of 2 scars above curved ventral row of 3 scars. Fulcral point well developed. Two mandiular scars antero-ventral to central muscle field. Two dorsal scars, anterior one below apex of valve, very long, sinuous; second scar half length of first, located approximately mid-hinge.

Sexual dimorphism apparent, males slightly longer and lower than females. Appendages unknown. Measurements: (mm) Length 0.66 - 0.67, Height 0.33 - 0.35.

Remarks: *P. dentata* is definitely bairdioid, especially with regard to its hinge, central muscle field and inner lamella. These features, together with a carapace which is rounded anteriorly and truncated posteriorly, exclude it from the Bythocypridae.

Occurrence: *P. dentata* is rare in Brisbane Water. It is unknown in Port Jackson and Botany Bay. It has been reported from Port Hedland (Hartmann, 1978) and it occurs on the Sahul Shelf and in Bass Strait (K.G. McKenzie, pers. comm. 1978).

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# Distributional Weber Transformation*

R. S. PATHAK AND R. K. PANDEY

ABSTRACT. It is shown that the classical Weber transform,

$$F(u) = \int_a^\infty t[J_\nu(tu)Y_\nu(au) - J_\nu(au)Y_\nu(tu)]f(t)dt$$

can be extended to a space of distributions $W'(a,\infty)$. An inversion formula is obtained and some applications of a resulting operational calculus are indicated.

## INTRODUCTION

The Weber transform

$$F(u) = \int_a^\infty C_\nu(tu,au)\, t\, f(t)dt, \tag{1}$$

where $C_\nu(tu,au) = J_\nu(tu)Y_\nu(au) - J_\nu(au)Y_\nu(tu)$, $a > 0$, $u > 0$ and $\nu$ is any real number, has been successfully used in the study of theory of heat conduction by Nicholson (1922). The precise conditions of validity of the inversion formula for (1) are due to Titchmarsh (1923) and are given in Theorem 1 below. Griffith extended the Weber transformation and applied the extension to the solution of certain heat conduction problems (Griffith, 1956; Griffith, 1957).

With the emergence of the theory of generalized functions many aspects of the theory of integral transforms have acquired a new, more general treatment. The methods of the theory of generalized functions have permitted a generalization of the classical results. This paper consists of a comprehensive and incisive description of a generalization of the Weber transform. The aim of the present paper is to extend classical Weber transformation to distributions and apply the theory thus developed to solve certain differential operator equations and Dirichlet's problem in cylindrical coordinates for a plate.

Our notations and terminology follow those of Zemanian (1968). We shall need the following formulae:

$$Y_\nu(xu) = J_\nu(xu)\cot\nu\pi - \operatorname{cosec}\nu\pi J_{-\nu}(xu) \tag{2}$$

$$S_{\mu,\nu}(z) = z^{\mu-2}\left[1 - \frac{(\mu-1)^2 - \nu^2}{z^2} + \frac{\{(\mu-1)^2 - \nu^2\}\{(\mu-3)^2 - \nu^2\}}{z^4} + \right] \tag{3}$$

$$J_\nu(z) = \left(\frac{2}{\pi z}\right)^{\frac{1}{2}}[\cos(z - \tfrac{1}{2}\nu\pi - \tfrac{1}{4}\pi) + O(1/|z|)] \quad \text{for large } z, \tag{4}$$

$$Y_\nu(z) = \left(\frac{2}{\pi z}\right)^{\frac{1}{2}}[\sin(z - \tfrac{1}{2}\nu\pi - \tfrac{1}{4}\pi) + O(1/|z|)] \quad \text{for large } z. \tag{5}$$

As $u \to \infty$,

$$C_\nu(tu,au) = -\frac{2}{\pi u\sqrt{at}}\Big\{\sin u(t-a) + \sin u(t-a) \times O(1/u) + \cos u(t-a) \times O(1/u)\Big\}$$

and

$$\frac{C_\nu(xu,au)}{J_\nu^2(au) + Y_\nu^2(au)} = -\sqrt{a/x}\Big\{\sin u(x-a) + \sin u(x-a) \times O(1/u) + \cos u(x-a) \times O(1/u)\Big\}. \tag{6}$$

As $u \to 0$,

$$\frac{1}{J_\nu^2(au) + Y_\nu^2(au)} = O(u^{2|\nu|})$$

and

$$C_\nu(xu,au) = -\frac{1}{\nu\pi}\Big\{(x/a)^\nu - (a/x)^\nu\Big\} + O(u). \tag{7}$$

Theorem 1

If $x > a > 0$ and $t^{\frac{1}{2}}f(t)$ is summable in the infinite interval $(a,\infty)$ and $f(t)$ is of bounded variation in a neighbourhood of $t = x$, then

$$\int_0^\infty \frac{C_\nu(xu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du \int_0^\infty C_\nu(tu,au)tf(t)dt = \tfrac{1}{2}\Big\{f(x+0) + f(x-0)\Big\} \tag{8}$$

the order $\nu$ being a real number.

## THE TESTING FUNCTION SPACE W(I)

Let I denote the open interval $(a,\infty)$. An infinitely differentiable function $\phi(x)$ defined over I is said to belong to W(I) if

$$\gamma_k(\phi) = \sup_{a<x<\infty} |\xi(x)\Delta_x^k(\phi(x)/x)| < \infty$$

for each $k = 0,1,2,\ldots$, where $\xi(x)$ is an infinitely

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differentiable function defined over $(a,\infty)$ which satisfies $\xi(x) > 0$ for all $x > a$ and

$$\xi(x) = O(x^{-3/2}), \quad x \to \infty,$$

and the operator $\Delta_x$ is defined by

$$\Delta_x = D_x^2 + \frac{1}{x} D_x - \frac{\nu^2}{x^2} \; ; \quad D_x = \frac{d}{dx} .$$

The topology on W(I) is defined by means of the separating collection of seminorms $\{\gamma_k\}_{k=0}^{\infty}$ (Zemanian, 1968). A sequence $\{\phi_\nu\}_{\nu=1}^{\infty}$ is said to converge in W(I) to the limit $\phi$ if $\gamma_k(\phi_\nu - \phi) \to 0$ as $\nu \to \infty$ for each $k = 0,1,2,\ldots$ . A sequence $\{\phi_\nu\}_{\nu=1}^{\infty}$ is said to be a Cauchy sequence in W(I) if $\gamma_k(\phi_\nu - \phi_\mu)$ goes to zero as $\nu$ and $\mu$ both go to infinite independently of each other. It can be readily seen that W(I) is a locally convex, sequentially complete Hausdorff topological vector space. The dual of the space W(I) will be represented by W'(I).

It may be remarked that the weight function $\xi(x)$ in the definition of the space W(I) is needed to ensure the differentiability of the distributional Weber transform, see Theorem 2.

Lemma 1

If $a > 0$ and $\nu$ is any real number, then for a fixed $y > 0$, $tC_\nu(ty,ay)$ as a function of t belongs to W(I).

Proof

Now

$$|\xi(t)\Delta_t^k(C_\nu(ty,ay))| = |(-1)^k y^{2k}\xi(t)C_\nu(ty,ay)|,$$

therefore for fixed $y > 0$

$$\sup_{a<t<\infty} |\xi(t)\Delta_t^k C_\nu(ty,ay)| < \infty .$$

WEBER TRANSFORMATION OF GENERALIZED FUNCTIONS

Let $f \in W'(I)$. For real $y > 0$ we define distributional Weber transformation of f by the relation

$$F(y) \triangleq (W_\nu f)y \triangleq \langle f(t), tC_\nu(ty,ay)\rangle , \qquad (9)$$

where $\nu$ is a real number, $a > 0$, and $C_\nu(ty,ay)$ is the same as defined by (1). From Lemma 1 we know that for fixed $y \neq 0$, $tC_\nu(ty,ay) \in W(I)$, the relation (9) is therefore meaningful.

Theorem 2

For real $y > 0$, let F(y) be defined by (9). Then F(y) is differentiable and that

$$F'(y) = \langle f(t), t \frac{\partial}{\partial y} C_\nu(ty,ay)\rangle \qquad (10)$$

for all real values of $\nu$.

Proof

We have

$$\frac{F(y+\Delta y) - F(y)}{y} - \langle f(t), t \frac{\partial}{\partial y} C_\nu(ty,ay)\rangle$$
$$= \langle f(t), t \frac{C_\nu(t[y+\Delta y], a[y+\Delta y]) - C_\nu(ty,ay)}{\Delta y} - t\frac{\partial}{\partial y} C_\nu(ty,ay)\rangle .$$

Now we have to show that

$$\Theta_{\Delta y}(t) \triangleq t \frac{C_\nu(t[y+\Delta y], a[y+\Delta y]) - C_\nu(ty,ay)}{\Delta y} - t\frac{\partial}{\partial y} C_\nu(ty,ay) \to 0$$

in W(I) as $\Delta y \to 0$. Now

$$\xi(t)\Delta_t^k\Theta_{\Delta y}(t) = \xi(t)(-1)^k \times \left[\frac{(y+\Delta y)^{2k}C_\nu(t[y+\Delta y], a[y+\Delta y]) - C_\nu(ty,ay)y^{2k}}{\Delta y} - \frac{\partial}{\partial y}\left(y^{2k}C_\nu(ty,ay)\right)\right]$$

$$= \xi(t)(-1)^k \left[\frac{1}{\Delta y}\int_y^{y+\Delta y} \frac{\partial}{\partial x}\{x^{2k}C_\nu(tx,ax)\}\,dx - \frac{\partial}{\partial y}\{y^{2k}C_\nu(ty,ay)\}\right]$$

$$= \xi(t)(-1)^k \left[\frac{1}{\Delta y}\int_y^{y+\Delta y} \frac{\partial}{\partial x}\{x^{2k}C_\nu(tx,ax)\}\,dx - \left\{\frac{\partial}{\partial x}\left(x^{2k}C_\nu(tx,ax)\right)_{x=y}\right\}\right]$$

$$= \xi(t)(-1)^k \frac{1}{\Delta y}\int_y^{y+\Delta y} dx \int_y^x \frac{\partial^2}{\partial\eta^2}\left[\eta^{2k}C_\nu(t\eta,a\eta)\right] d\eta .$$

Therefore

$$|\xi(t)\Delta_t^k\Theta_{\Delta y}(t)| \le |\Delta y| \sup_{\substack{a<t<\infty \\ y-\Delta y\le\eta\le y+\Delta y}} \left|\xi(t)\frac{d^2}{d\eta^2}\left[\eta^{2k}C_\nu(t\eta,a\eta)\right]\right| .$$

Hence

$$|\xi(t)\Delta_t^k\Theta_{\Delta y}(t)| \le |\Delta y| \sup_{\substack{a<t<\infty \\ y-|\Delta y|\le\eta\le y+|\Delta y|}} \Big|\xi(t)\Big[t^2J_\nu''(t\eta)Y_\nu(a\eta)\eta^{2k} - t^2Y_\nu''(t\eta)J_\nu(a\eta)\eta^{2k} + a^2J_\nu(t\eta)Y_\nu''(a\eta)\eta^{2k} - a^2Y_\nu(t\eta)J_\nu''(a\eta)\eta^{2k} + 4ktJ_\nu'(t\eta)Y_\nu(a\eta)\eta^{2k-1} + 4kaJ_\nu(t\eta)Y_\nu'(a\eta)\eta^{2k-1} - 4ktY_\nu'(t\eta)J_\nu(a\eta)\eta^{2k-1} - 4kaY_\nu(t\eta)J_\nu'(a\eta)\eta^{2k-1} + 2k(2k-1)J_\nu(t\eta)Y_\nu(a\eta)\eta^{2k-2} - 2k(2k-1)Y_\nu(t\eta)J_\nu(a\eta)\eta^{2k-2}\Big]\Big| .$$

In view of the asymptotic behaviours of Bessel functions and their derivatives for large values of t, we can find a positive constant Q such that $(t\eta)^{\frac{1}{2}}J_\nu''(t\eta)$, $(t\eta)^{\frac{1}{2}}Y_\nu''(t\eta)$, $(t\eta)^{\frac{1}{2}}J_\nu(t\eta)$, $(t\eta)^{\frac{1}{2}}Y_\nu(t\eta)^{\frac{1}{2}}$, $(t\eta)^{\frac{1}{2}}J_\nu'(t\eta)$ and $(t\eta)^{\frac{1}{2}}Y_\nu'(t\eta)$ are bounded by Q.

Since $\eta \in [\frac{1}{2}y, \frac{3}{2}y]$, for fixed positive y, $|(a\eta)^{\frac{1}{2}}Y_\nu(a\eta)|$ and $|(a\eta)^{\frac{1}{2}}J_\nu(a\eta)|$ are bounded, therefore we get

$$\begin{aligned}
&|\xi(t)\Delta_t^k\theta_{\Delta y}(t)| \\
&\leq |\Delta y|\Big[Qa^{-\frac{1}{2}}A_1\eta^{2k-1} + Qa^{-\frac{1}{2}}A_2\eta^{2k-1} \\
&+ Qa^{3/2}A_3\eta^{2k-1} + Qa^{3/2}A_4\eta^{2k-1} + 4kQa^{-\frac{1}{2}}A_5\eta^{2k-2} \\
&+ 4kQa^{\frac{1}{2}}A_6\eta^{2k-2} + 4kQa^{-\frac{1}{2}}A_7\eta^{2k-2} + 4kQa^{\frac{1}{2}}A_8\eta^{2k-2} \\
&+ 2k(2k-1)Aa^{-\frac{1}{2}}A_9\eta^{2k-3} \\
&+ 2k(2k-1)Qa^{-\frac{1}{2}}A_{10}\eta^{2k-3}\Big], \qquad (11)
\end{aligned}$$

where $A_i$ $(i = 1,\ldots,10)$ are appropriate constants. Therefore there exist constants $B_1$, $B_2$ and $B_3$ such that

$$\begin{aligned}
&|\xi(t)\Delta_t^k\theta_{\Delta y}(t)| \\
&\leq |\Delta y|\Big[B_1\eta^{2k-1} + B_2\eta^{2k-2} + B_3\eta^{2k-3}\Big] \\
&\leq |\Delta y|\Big[B_1 \sup_{\frac{1}{2}y<\eta<\frac{3}{2}y} \eta^{2k-1} \\
&\quad + B_2 \sup_{\frac{1}{2}y<\eta<\frac{3}{2}y} \eta^{2k-2} \\
&\quad + B_3 \sup_{\frac{1}{2}y<\eta<\frac{3}{2}y} \eta^{2k-3}\Big] \\
&\leq |\Delta y|\left[B_1\frac{(\frac{3}{2}y)^{2k}}{(\frac{1}{2}y)} + B_2\frac{(\frac{3}{2}y)^{2k}}{(\frac{1}{2}y)^2} + B_3\frac{(\frac{3}{2}y)^{2k}}{(\frac{1}{2}y)^3}\right] \\
&\to 0 \text{ as } \Delta y \to 0 .
\end{aligned}$$

This completes the proof of Theorem 2.

Theorem 3

For real $y > 0$, let $F(y)$ be defined as in (9), then

$$F(y) = O(y^{-|\nu|-\frac{1}{2}}) \text{ as } y \to 0$$

and

$$F(y) = O(y^{2r-1}) \quad \text{as } y \to \infty$$

where r is some non-negative integer.

Proof

Assume at first that $\nu > 0$. In view of the result (Zemanian, 1968), there exists a constant $C > 0$ and a non-negative integer r such that

$$\begin{aligned}
|F(y)| &= |\langle f(t), tC_\nu(ty,ay)\rangle| \\
&\leq C \max_{0\leq k\leq r} \gamma_k\big(tC_\nu(ty,ay)\big) \\
&= C \max_{0\leq k\leq r} \sup_{a<t<\infty} |\xi(t)(-1)^k y^{2k} C_\nu(ty,ay)| = \\
&= C \max_{0\leq k\leq r} \sup_{a<t<\infty} |\xi(t)y^{2k}(ty)^{-\frac{1}{2}} \\
&\quad \times \Big[(ty)^{\frac{1}{2}}J_\nu(ty)Y_\nu(ay) - (ty)^{\frac{1}{2}}Y_\nu(ty)J_\nu(ay)\Big]| .
\end{aligned}$$

The function $(ty)^{\frac{1}{2}}J_\nu(ty)$ is bounded for all $t > a$, $y > 0$ and the function $(ty)^{\frac{1}{2}}Y_\nu(ty)$ is bounded for all $t > a$, $y > 0$ except when $(ty) \to 0$. As $t > a$, $(ty) \to 0$ implies $y \to 0$ . In this case $ay = O(ty)$ and $|Y_\nu(ty)J_\nu(ay)| = O(1)$. Also, as $(ty) \to 0$,

$$\begin{aligned}
&J_0(ty)Y_0(ay) - Y_0(ty)J_0(ay) \\
&= J_0(ty)J_0(ay)\log(a/t) = O(1).
\end{aligned}$$

Thus, for $\nu \geq 0$, as $y \to 0$

$$\begin{aligned}
|F(y)| &\leq C \max_{0\leq k\leq r} \sup_{a<t<\infty} \xi(t) \\
&\quad \times \Big[A(ty)^{-\frac{1}{2}}(ay)^{-\nu} + B\Big]y^{2k}.
\end{aligned}$$

Therefore

$$F(y) = O(y^{-\nu-\frac{1}{2}}), \qquad y \to 0+.$$

Also, as $y \to \infty$

$$\begin{aligned}
F(y) &\leq C \max_{0\leq k\leq r} \sup_{a<t<\infty} \xi(t) \\
&\quad \times \Big[A(ty)^{-\frac{1}{2}}(ay)^{-\frac{1}{2}} + D(ty)^{-\frac{1}{2}}(ay)^{-\frac{1}{2}}\Big]y^{2k} \\
&\leq C' \max_{0\leq k\leq r} \sup_{a<t<\infty} \xi(t)t^{-\frac{1}{2}}y^{2k-1}.
\end{aligned}$$

Therefore

$$F(y) = O(y^{2r-1}), \qquad y \to \infty.$$

The above conclusion is also true for negative values of $\nu$ as the function $C_\nu(xu,au)$ is an even function of $\nu$.

Lemma 2

Let $\nu$ be any real number and let $t > a$, then for fixed $x > 0$,

$$t\int_0^\eta C_\nu(xu,au)\,\frac{C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\,u\,du \to 0$$

in $W(I)$ as $\eta \to 0+$.

Proof

Assume at first that $\nu > 0$. Then

$$\begin{aligned}
&\xi(t)\Delta_t^k \int_0^\eta C_\nu(xu,au)\,\frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du \\
&= \xi(t)\Delta_t^k \int_0^\eta \Big[J_\nu(xu)Y_\nu(au) - Y_\nu(xu)J_\nu(au)\Big] \\
&\times \Big[J_\nu(tu)Y_\nu(au) - Y_\nu(tu)J_\nu(au)\Big]\,\frac{u\,du}{J_\nu^2(au)+Y_\nu^2(au)} =
\end{aligned}$$

$$= \xi(t)\Delta_t^k \int_0^\eta \Big[J_\nu(xu)J_\nu(tu)Y_\nu^2(au) - J_\nu(xu)Y_\nu(au)Y_\nu(tu)J_\nu(au) - Y_\nu(xu)J_\nu(au)J_\nu(tu)Y_\nu(au) + Y_\nu(xu)Y_\nu(tu)J_\nu^2(au)\Big] \times \frac{u\,du}{J_\nu^2(au)+Y_\nu^2(au)}. \tag{12}$$

Considering the first term within the bracket

$$\xi(t)\Delta_t^k \int_0^\eta \Big[J_\nu(xu)J_\nu(tu)Y_\nu^2(au)\Big] \frac{u\,du}{J_\nu^2(au)+Y_\nu^2(au)}$$

$$= \xi(t)\int_0^\eta (-1)^k u^{2k} J_\nu(xu)Y_\nu^2(au)(tu)^{-\frac12} \Big[(tu)^{\frac12}J_\nu(tu)\Big]\frac{u\,du}{J_\nu^2(au)+Y_\nu^2(au)}$$

$$\le C\,\frac{\xi(t)}{t^{\frac12}}\,\frac{(-1)^k}{x^{\frac12}}\int_0^\eta u^{2k}\left[\frac{Y_\nu^2(au)}{J_\nu^2(au)+Y_\nu^2(au)}\right]du$$

$$\le C'\,\frac{\eta^{2k+1}}{2k+1} \to 0 \qquad \text{as } \eta \to 0+$$

because as $u \to 0$,

$$\left[\frac{Y_\nu^2(au)}{J_\nu^2(au)+Y_\nu^2(au)}\right] = O(1)$$

and $\dfrac{\xi(t)}{t^{\frac12}}$ is bounded for all $t > a$.

Similarly it can be shown that the other terms in (12) also tend to zero as $\eta \to 0+$. The case when $\nu$ is negative can similarly be disposed off.

Lemma 3

Let $f \in W'(I)$ and $C_\nu(tu,au)$ be the same as defined by (1), then for fixed $x, N > 0$,

$$\int_0^N \langle f(t), tC_\nu(tu,au)\rangle \frac{C_\nu(xu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du$$

$$= \left\langle f(t), t\int_0^N C_\nu(tu,au)\frac{C_\nu(xu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\right\rangle. \tag{13}$$

Proof

In view of Theorems 2 and 3, the integral in the left hand side of (13) exists (meaningful). It can be shown that for fixed $x > 0$, the integral appearing in the right hand side of the expression in (13) belongs to $W(I)$. So the right hand side expression in (13) is meaningful. To justify the equality (13) we first show by using the technique of Riemann sums (Pandey and Zemanian, 1968), that for $\eta > 0$,

$$\int_\eta^N \langle f(t), tC_\nu(tu,au)\rangle \frac{C_\nu(xu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du$$

$$= \left\langle f(t), \int_\eta^N tC_\nu(tu,au)\frac{C_\nu(xu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\right\rangle. \tag{14}$$

Now using Lemma 2 and letting $\eta \to 0+$ in (14) the result (13) follows.

INVERSION OF THE DISTRIBUTIONAL WEBER TRANSFORM

Let us write

$$W_N(t,x) = \int_0^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du.$$

For $y > 0$ define

$$\Psi_N(t,y) = \int_a^y xW_N(t,x)\,dx$$

$$= \int_0^N \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du \int_a^y xC_\nu(xu,au)\,dx.$$

Let

$$\int_a^y C_\nu(xu,au)x\,dx = C_\nu^*(y,a,u);$$

then

$$\Psi_N(t,y) = \int_0^N \frac{C_\nu(tu,au)C_\nu^*(y,a,u)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du. \tag{15}$$

Lemma 4

For fixed $y > 0$ and $x > a > 0$,

$$\lim_{N\to\infty}\Psi_N(x,y) = \begin{cases} 1 & (a < x < y) \\ 0 & (x > y) \end{cases}$$

Proof

Let us define a step function $f(\xi)$ by

$$f(\xi) = \begin{cases} 1 & (a < \xi < y) \\ 0 & (\xi > y) \end{cases}$$

Then, $f(\xi)$ satisfies conditions of Theorem 1, and hence from (8) we have

$$\lim_{N\to\infty}\int_0^N \frac{C_\nu(xu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\int_a^y tC_\nu(tu,au)\,dt$$

$$= 1 \quad (a < x < y)$$

$$= 0 \quad (x > y).$$

Now using (15) we get

$$\lim_{N\to\infty} \Psi_N(x,y) = 1 \qquad (a < x < y)$$
$$= 0 \qquad (x > y).$$

Lemma 5

Let c and d (> c) be two positive numbers. Then

$$\lim_{N\to\infty} \int_c^d xW_N(t,x)\,dx = \begin{cases} 1 & t \in (c,d) \\ 0 & t \notin [c,d] \end{cases}$$

Proof

Setting

$$f(t) = \begin{cases} 1 & a \le c < t < d \\ 0 & t > d \end{cases}$$

in Theorem 1, we get

$$\lim_{N\to\infty} \int_0^N \frac{C_\nu(xu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du \int_c^d C_\nu(tu,au)t\, dt$$

$$= \lim_{N\to\infty} \int_c^d W_N(t,x)t\, dt$$

$$= \begin{cases} 1 & x \in (c,d) \\ 0 & x \notin [c,d] \end{cases}$$

Lemma 6

For $0 < a < t \le b_1$, $0 < a_2 \le x \le b_2$ and $N > 0$, the function $(x-t)W_N(t,x)$ is bounded uniformly for all $x,t,N > 0$, $\nu$ being any real number, and $W_N(t,x)$ is bounded for the x and t satisfying $|t-x| \ge \delta > 0$.

Proof

Let us consider first the case $0 < N \le 1$.

$$(x-t)W_N(t,x) = (x-t)\int_0^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du.$$

Using the definition of $Y_\nu(x)$ as given in (2) we can write

$$(x-t)W_N(t,x) = (x-t)$$

$$\times \int_0^N \frac{[J_\nu(au)J_{-\nu}(xu) - J_\nu(xu)J_{-\nu}(au)]\times}{\sin^2\nu\pi J_\nu^2(au) + } ---$$

$$--- \frac{\times[J_\nu(au)J_{-\nu}(tu) - J_\nu(tu)J_{-\nu}(au)]}{+[J_\nu(au)\cos\nu\pi - J_{-\nu}(au)]^2}\, u\, du.$$

Since for $a < t \le b_1$ and $a_2 \le x \le b_2$, $au = O(tu)$ and also $au = O(xu)$ as $u \to 0$, we conclude that $J_{\pm\nu}(au)J_{\pm\nu}(xu)$, $J_{\pm\nu}(au)J_{\pm\nu}(xu)$ are all bounded when $u \to 0$. Therefore

$$|(x-t)W_N(t,x)| \le B_1|(x-t)| \times$$

$$\times \int_0^N \frac{u\, du}{|J_\nu^2(au) + J_{-\nu}^2(au) - 2J_\nu(au)J_{-\nu}(au)\cos\nu\pi|} \le$$

$$\le B_2|(x-t)| \int_0^N u^{2|\nu|+1}\, du$$

$$\le B_2|x-t| \frac{N^{2|\nu|+2}}{2|\nu|+2} < \frac{B_2|x-t|}{2|\nu|+2} < B_3,$$

where $B_3$ is constant independent of x, t and N. Next consider the case $N > 1$.

$$|(x-t)W_N(t,x)|$$

$$\le \left| \int_0^1 \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du \right| |x-t|$$

$$+ \left| \int_1^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du \right| |x-t|.$$

Since the first integral is bounded, we consider the second

$$(x-t)\int_1^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du$$

$$= \sqrt{(a/x)}\,\frac{2(x-t)}{\pi\sqrt{at}} \int_1^N [\sin u(t-a) + \sin u(t-a)O(1/u)$$

$$+ \cos u(t-a)O(1/u)]\times[\sin u(x-a)$$

$$+ \sin u(x-a)O(1/u) + \cos u(x-a)O(1/u)]du$$

$$= \frac{(x-t)}{\pi\sqrt{xt}} \int_1^N [\cos u(t-x) - \cos u(t+x-2a) + 2\big(\cos u(t-x)$$

$$- \cos u(t+x-2a) + \sin u(x+t-2a)\big)O(1/u)$$

$$+ 2\big(\cos u(t-x) + \sin u(t+x-2a)\big)O(1/u^2)]du.$$

Since each of the above integrals is bounded, therefore

$$|(x-t)| \left| \int_1^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)}\, u\, du \right| < B_4,$$

$B_4$ being independent of x, t and N. The proof of the second part is obvious.

Corollary

For $0 < a < t \le b_1$, $0 < c \le d$ and $N > 0$,

$$\int_c^d |(x-t)W_N(t,x)|dx < \infty.$$

Lemma 7

For $c + \delta < t < b$,

$$\int_c^{t-\delta} W_N(t,x)x\, dx \to 0$$

as $N \to \infty$ uniformly for $c + \delta < t < b$, $\delta > 0$.

Proof

We have

$$\int_c^{t-\delta} W_N(t,x)x\,dx$$

$$= \int_c^{t-\delta}\left[\int_0^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\right]x\,dx$$

$$= \int_c^{t-\delta} x\,dx \int_0^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du$$

$$= \int_c^{t-\delta} x\,dx\left[\left(\int_0^\infty - \int_N^\infty\right)\frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\right]$$

$$= \int_0^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\int_0^{t-\delta} C_\nu(xu,au)x\,dx$$

$$- \int_N^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\int_c^{t-\delta} C_\nu(xu,au)x\,dx.$$

Since by Lemma 5 the first integral on the right-hand side is equal to zero, therefore

$$\int_c^{t-\delta} W_N(t,x)x\,dx$$

$$= -\int_N^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\int_c^{t-\delta} C_\nu(xu,au)x\,dx.$$

Now we shall show that the integral on the right-hand side $\to 0$ as $N \to \infty$ uniformly for all $t \in (c+\delta,b)$. Now

$$\int_N^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\int_c^{t-\delta} C_\nu(xu,au)x\,dx$$

$$= \int_N^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\int_c^{t-\delta}[J_\nu(xu)Y_\nu(au) - Y_\nu(xu)J_\nu(au)]x\,dx$$

$$= \int_N^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\left[Y_\nu(au)\int_c^{t-\delta} xJ_\nu(xu)\,dx - J_\nu(au)\int_c^{t-\delta} xY_\nu(xu)\,dx\right]$$

$$= \int_N^\infty \frac{C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\,u\,du\Big[\frac{1}{u^2}Y_\nu(au)\times \times\Big\{\nu(xu)J_\nu(xu)S_{0,\nu-1}(xu) - (xu)J_{\nu-1}(xu)S_{1,\nu}(xu)\Big\}_{cu}^{u(t-\delta)}$$
$$- \frac{1}{u^2}J_\nu(au)\Big\{\nu(xu)Y_\nu(xu)S_{0,\nu-1}(xu) - (xu)Y_{\nu-1}(xu)S_{1,\nu}(xu)\Big\}_{cu}^{u(t-\delta)}\Big]$$

$$= \int_N^\infty (-\sqrt{a/t})\Big\{\sin u(t-a) + \sin u(t-a)\times \times O(\tfrac{1}{u}) + \cos u(t-a)O(\tfrac{1}{u})\Big\}\times$$
$$\Big[\frac{1}{u^2}Y_\nu(au)\Big\{\nu(t-\delta)u^2J_\nu(t-\delta)u^2S_{0,\nu-1}(t-\delta)u^2 - (t-\delta)u^2J_{\nu-1}(t-\delta)u^2S_{1,\nu}(t-\delta)u^2$$
$$- \nu(cu^2)J_\nu(cu^2)S_{0,\nu-1}(cu^2) + (cu^2)J_{\nu-1}(cu^2)S_{1,\nu}(cu^2)\Big\}$$
$$-\frac{1}{u^2}J_\nu(au)\Big\{\nu(t-\delta)u^2Y_\nu[(t-\delta)u^2]S_{0,\nu-1}[(t-\delta)u^2] - (t-\delta)u^2Y_{\nu-1}[(t-\delta)u^2]S_{1,\nu}[(t-\delta)u^2]$$
$$- \nu(cu^2)Y_\nu(cu^2)S_{0,\nu-1}(cu^2) + (cu^2)Y_{\nu-1}(cu^2)S_{1,\nu}(cu^2)\Big\}\Big]u\,du.$$

Now substituting the asymptotic expressions for the Bessel and Lommel functions from equations (3), (4), (5) and then evaluating the integrals thus obtained, it can be shown by simple computation that they all tend to zero separately as $N \to \infty$.

Lemma 8

Let $a < t < d-\delta$ and $\delta > 0$, then

$$\int_{t+\delta}^{d} W_N(t,x)x\,dx \to 0$$

as $N \to \infty$ for all $t \in (a,d-\delta)$.

Proof

The proof is based on the conclusion of Lemma 5 and the technique is similar to that used in the proof of Lemma 7.

Lemma 9

Let $\phi(x) \in \mathcal{D}(I)$ and its support be contained in $[c,d]$ where $0 < c < d$. Let $c + \delta \le t \le d$, $\delta > 0$, then

$$\int_c^{t-\delta} W_n(t,x)x\phi(x)dx \to 0$$

as $N \to \infty$ uniformly for all $t \in [c+\delta,d]$.

Proof

The proof can be given by following the technique of Hobson (1950). By the second part of Lemma 6 there exists a positive constant K such that $|xW_N(t,x)| < K$ uniformly for all $x \in [c,d]$, $t \in [c+\delta,d]$ and $N > 0$.

In view of the uniform continuity of $\phi(x)$ in $c \le x \le d$ for a given arbitrary $\varepsilon > 0$, we can find a continuous function $\chi(x)$ such that

$$\int_c^{t-\delta} |\phi(x) - \chi(x)|dx \le \int_c^{d-\delta} |\phi(x) - \chi(x)|dx < \frac{\varepsilon}{K}.$$

The interval $(c,t-\delta)$ may be divided into subintervals $(c,x_1)$, $(x_1,x_2)$ ... $(x_{n-1},t-\delta)$, so chosen that the fluctuation of $\chi(x)$ in each of these intervals is less than $\varepsilon/K(d-\delta-c)$. Let $\psi(x)$ be a function which, in the interior of each part $(x_{r-1},x_r)$, where $r = 1,2,3, \ldots,n$ has the constant value $Q_r = (x_r + x_{r-1})/2$. At the extremities of the parts, we take $\psi(x)$ to have the value zero. Thus $\psi(x)$ has the finite set of values $Q_1$, $Q_2$, $Q_3$, ..., $Q_n$, 0. Since $|\chi(x) - \psi(x)| < \varepsilon/K(d-\delta-c)$ everywhere except at the end points of n subintervals of $(c,t-\delta)$, we have

$$\int_c^{t-\delta} |\chi(x) - \psi(x)|dx < \frac{\varepsilon}{K},$$

and therefore

$$\int_c^{t-\delta} |\phi(x) - \psi(x)|dx < \frac{2\varepsilon}{K}.$$

Now

$$\begin{aligned}
&\left|\int_c^{t-\delta} \phi(x)xW_N(t,x)dx\right| \\
&\le \left|\int_c^{t-\delta} \{\phi(x) - \psi(x)\}xW_N(t,x)dx\right| + \sum_{r=1}^{n} |Q_r| \left|\int_{x_{r-1}}^{x_r} xW_N(t,x)dx\right| \\
&\le \left|\int_c^{t-\delta} |\phi(x) - \psi(x)|\,|xW_N(t,x)|dx\right| + \sum_{r=1}^{n} |Q_r| \left|\int_{x_{r-1}}^{x_r} xW_N(t,x)dx\right| \\
&< 2\varepsilon + \sum_{r=1}^{n} |Q_r| \left|\int_{x_{r-1}}^{x_r} xW_N(t,x)dx\right|
\end{aligned}$$

Since t lies outside the interval $(x_{r-1},x_r)$ for each $r = 1,2,3, \ldots$, in view of Lemma 7,

$$\left|\int_{x_{r-1}}^{x_r} xW_N(t,x)dx\right| \to 0$$

independently of $t \in [c+\delta,d]$ as $N \to \infty$. A positive number $N_\varepsilon$ (independent of x) can be so chosen that

$$\left|\int_{x_{r-1}}^{x_r} xW_N(t,x)dx\right| < \frac{\varepsilon}{\sum_{r=1}^{n} |Q_r|}$$

for $r = 1,2,3, \ldots$ and for all values of $t \in [c+\delta,d]$. Thus

$$\left|\int_c^{t-\delta} \phi(x)xW_N(t,x)dx\right| < 3\varepsilon$$

provided $N \ge N_\varepsilon$ for all values of $t \in [c+\delta,d]$.

Lemma 10

Let $\phi(x) \in \mathcal{D}(I)$ and its support be contained in $[c,d]$ where $0 < c < d$. Let $a < t < d-\delta$, $c > 2\delta > 0$ then

$$\int_{t+\delta}^{d} W_N(t,x)\phi(x)x\,dx \to 0$$

as $N \to \infty$ uniformly for all $t \in (a,d-\delta)$.

Proof

Assume at first that $\phi(x)$ is an infinitely differentiable real valued function defined on $[t+\delta,d]$, $a < t < d-\delta$. Then $\phi(x)$ is a function of bounded variation on $[t+\delta,d]$ (Rudin, 1964). Consequently, there exist monotonically increasing functions $p(x)$ and $q(x)$ on $[t+\delta,d]$ with $p(t+\delta) = q(t+\delta) = 0$ such that (Rudin, 1964)

$$\phi(x) = \phi(t+\delta) + p(x) - q(x) \qquad (t+\delta \le x \le d).$$

Hence

$$\begin{aligned}
\int_{t+\delta}^{d} W_N(t,x)\phi(x)x\,dx &= \phi(t+\delta)\int_{t+\delta}^{d} W_N(t,x)\phi(x)x\,dx \\
&+ \int_{t+\delta}^{d} p(x)W_N(t,x)\phi(x)x\,dx \\
&+ \int_{t+\delta}^{d} q(x)W_N(t,x)\phi(x)x\,dx.
\end{aligned}$$

The result now can be proved by using mean value theorem of integral calculus followed by variation of techniques used in the proof of Lemma 7 and 8.

The proof for infinitely differentiable

complex valued function $\phi(x)$ can be given by separating it into its real and imaginary parts.

Lemma 11

Let $\phi(x) \in \mathcal{D}(I)$ and its support be contained in $[c,d]$, where $0 < c < d$. Then

$$t \int_c^d W_N(t,x)\phi(x)x\, dx \to t\phi(t)$$

in $W(I)$ as $N \to \infty$.

Proof

It can be easily seen that

$$\Delta_t W_N(t,x) = \Delta_x W_N(t,x) .$$

Hence

$$\Delta_t \int_c^d W_N(t,x)\phi(x)x\, dx = \int_c^d [\Delta_x W_N(t,x)]\phi(x)x\, dx$$

$$= \int_c^d W_N(t,x)[\Delta_x \phi(x)]x\, dx$$

by integrating by parts. Operating by $\Delta_t$ successively, it can be seen in view of Lemma 5 that

$$\lim_{N\to\infty} \xi(t)\ \Delta_t^k (1/t)\left[t \int_c^d W_N(t,x)\phi(x)\ x dx - t\phi(t)\right]$$

$$= \lim_{N\to\infty} \xi(t) \int_c^d W_N(t,x)[\phi_k(x) - \phi_k(t)]x\, dx$$

where

$$\phi_k(x) = \Delta_x^k\ \phi(x) \qquad (k = 0,1,2, \ldots).$$

Therefore our problem is reduced to proving the following result

$$\lim_{N\to\infty} \xi(t) \int_c^d W_N(t,x)[\psi(x) - \psi(t)]x\, dx = 0$$

uniformly for all $t$, where $\psi(x) \in \mathcal{D}(I)$. Assuming that $\delta$ is a positive number less than $\frac{1}{2}\min(1,c,a)$, for $t > a$ we write

$$I = \xi(t) \int_c^d W_N(t,x)[\psi(x) - \psi(t)]x\, dx$$

$$= \xi(t)\left(\int_c^{t-\delta} + \int_{t-\delta}^{t+\delta} + \int_{t+\delta}^{d}\right) W_N(t,x)[\psi(x) - \psi(t)]x\, dx$$

$$= I_1 + I_2 + I_3 \text{ (say)}.$$

Now we notice that $I_2 = 0$ for $t \geq d+\delta$ and also for $t \leq c-\delta$, hence we consider the case $c-\delta < t < d+\delta$.

$$|I_2| \leq \xi(t) \int_{t-\delta}^{t+\delta} |\psi(x) - \psi(t)|\ |xW_N(t,x)|dx$$

$$\leq \xi(t) \int_{t-\delta}^{t+\delta} |xW_N(t,x)|dx \left|\int_t^x \psi'(\eta)d\eta\right|$$

$$\leq \sup_{t-\delta<\eta<t+\delta} |\psi'(\eta)|\xi(t) \int_{t-\delta}^{t+\delta} |(x-t)W_N(t,x)|x\, dx$$

$$\leq \sup_{c<\eta<d} |\psi'(\eta)|\xi(t) \int_{t-\delta}^{t+\delta} |(x-t)W_N(t,x)|x\, dx.$$

Using Lemma 6 we can find a positive constant $M$ such that $|I_2| < \delta M$. Now for arbitrary $\varepsilon > 0$, choose $\delta$ such that $\delta M < \varepsilon/8$. Therefore

$$|I_2| < \frac{\varepsilon}{4} \text{ for all } t \in (a,\infty) . \tag{16}$$

Next consider

$$I_1 = \xi(t) \int_c^{t-\delta} W_N(t,x)[\psi(x)-\psi(t)]x\, dx$$

$$= I_{1,1} - I_{1,2} \text{ (say)}$$

where

$$I_{1,1} = \xi(t) \int_c^{t-\delta} W_N(t,x)\psi(x)x\, dx$$

and

$$I_{1,2} = \xi(t)\psi(t) \int_c^{t-\delta} W_N(t,x)x\, dx .$$

Clearly $I_{1,2} = 0$ if $t \notin (c,d)$. For $t \in (c,d)$

$$|I_{1,2}| \leq d\gamma_0(\psi)\left| \int_c^{t-\delta} W_N(t,x)x\, dx\right| \to 0$$

as $N \to \infty$ uniformly for all $t \in (c,d)$ in view of Lemma 7, so that

$$\lim_{N\to\infty} I_{1,2} = 0 \tag{17}$$

uniformly for all $t > a$. Now denoting the bound of $|\psi(x)|$ by $M$, we have

$$|I_{1,1}| \leq \xi(t) \int_c^{t-\delta} |\psi(x)|\ |xW_N(t,x)|dx$$

$$\leq \xi(t) \int_c^d |\psi(x)|\ |xW_N(t,x)|dx$$

$$\leq M\xi(t) \int_c^d \left|x \int_0^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au) + Y_\nu^2(au)} u\, du\right| dx$$

$$\le M\xi(t)\int_c^d x\,dx\left[\left|\int_0^1 \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}u\,du\right| + \left|\int_1^N \frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}u\,du\right|\right]$$

$$\le M\xi(t)t^{-\frac{1}{2}}\int_c^d x\,dx\left[\left|\int_0^1 \frac{C_\nu(xu,au)C_\nu(tu,au)(tu)^{\frac{1}{2}}}{J_\nu^2(au)+Y_\nu^2(au)}u^{\frac{1}{2}}du\right| + \left|\int_1^N t^{\frac{1}{2}}\frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}u\,du\right|\right].$$

By the same arguments as used in the proof of Theorem 3, it can be shown that for $0<u<1$ there exists a constant B such that $|(tu)^{\frac{1}{2}}C_\nu(tu,au)| \le Bu^\lambda$, where $\lambda = -|\nu|$ or $\frac{1}{2}$ according as $(tu)\to\infty$ or $(tu)\to 0$. Therefore we have

$$|I_{1,1}| \le M\xi(t)t^{-\frac{1}{2}}\left\{B\int_c^d x\,dx\int_0^1\left|\frac{C_\nu(xu,au)}{J_\nu^2(au)+Y_\nu^2(au)}\right|u^{\frac{1}{2}+\lambda}du + \int_c^d x\,dx\left|\int_1^N t^{\frac{1}{2}}\frac{C_\nu(xu,au)C_\nu(tu,au)}{J_\nu^2(au)+Y_\nu^2(au)}u\,du\right|\right\}$$

$$\le M\xi(t)t^{-\frac{1}{2}}\Bigg[B\int_c^d x\,dx\left\{\int_0^1\left|[-\frac{1}{\nu\pi}\left((x/a)^\nu-(a/x)^\nu\right) + O(u)]\cdot O(u^{2|\nu|})\right|u^{\frac{1}{2}+\lambda}du\right\}$$
$$+\int_c^d x\,dx\Bigg|\int_1^N t^{\frac{1}{2}}\sqrt{a/x}\,[\sin u(x-a) + \sin u(x-a)\cdot O(1/u) + \cos u(x-a)\cdot O(1/u)]$$
$$\times\frac{2}{\pi u\sqrt{at}}[\sin u(t-a) + \sin u(t-a)\cdot O(1/u) + \cos u(t-a)\cdot O(1/u)]u\,du\Bigg|\Bigg]$$

$$\le M\xi(t)t^{-\frac{1}{2}}\Bigg|B\int_c^d x\,dx\left\{\int_0^1 |(-\frac{1}{\nu\pi})\left((x/a)^\nu-(a/x)^\nu\right)\cdot O(u^{2|\nu|+\frac{1}{2}+\lambda})|du + O\left(\int_0^1 u^{2|\nu|+3/2+\lambda}du\right)\right\}$$
$$+\int_c^d x^{\frac{1}{2}}dx\left(\frac{1}{\pi}\right)\Bigg|\int_1^N [\cos u(x-t) - \cos u(x+t-2a) + 2(\cos u(x-t) - \cos u(x+t-2a)$$
$$+\sin u(x+t-2a))\cdot O(1/u) + 2\cos u(x-t) + \sin u(x+t-2a))\cdot O(1/u^2)du]\Bigg|\Bigg]$$

$$\le M\xi(t)t^{-\frac{1}{2}}\Bigg[\Bigg|B_1\left(\frac{1}{\nu\pi}\right)\left(\frac{1}{2|\nu|+\lambda+3/2}\right)\left(\frac{d^{\nu+2}}{a(\nu+2)} - \frac{c^{\nu+2}}{a(\nu+2)} + \frac{ac^{2-\nu}}{2-\nu} - \frac{ad^{2-\nu}}{2-\nu}\right) + B_2\left(\frac{1}{2|\nu|+\lambda+5/2}\right)\left(\frac{d^2}{2}-\frac{c^2}{2}\right)\Bigg|$$
$$+\left(\frac{1}{\pi}\right)\int_c^d x^{\frac{1}{2}}dx\Bigg|\int_1^N [\cos u(x-t) - \cos u(x+t-2a) + 2(\cos u(x-t) - \cos u(x+t-2a))\cdot O(1/u)$$
$$+ 2(\cos u(x-t) + \sin u(x+t-2a))\cdot O(1/u^2)]du\Bigg|\Bigg].$$

In the above integral each term can be shown to be bounded as in Lemma 6. Thus there exist constants Q > 0 and L > d+δ such that

$$|I_{1,1}| \le Q\xi(t)t^{-\frac{1}{2}} < \varepsilon \tag{18}$$

uniformly for $\forall t > L$. Now consider $c+\delta \le t \le L$. $I_{1,1}$ tends to zero uniformly for all $t \in [c+\delta, L]$ by Lemma 9. Since $\sup_{c+\delta\le T\le L}\xi(t)$ is bounded, we conclude from (18) that

$$|I_{1,1}| \to 0 \quad \text{as} \quad N\to\infty \tag{19}$$

uniformly for all $t \ge c+\delta$. But $I_{1,1} = 0$ for $t < c+\delta$. Therefore in view of (18) and (19)

$$\lim_{N\to\infty}|I_{1,1}| = 0 \tag{20}$$

uniformly for all $t > a$. Combining (17) and (20) it follows that

$$\lim_{N\to\infty} I_1 = 0 \tag{21}$$

uniformly for all $\forall t > a$. Similarly we can show that

$$\lim_{N\to\infty} I_3 = 0 \tag{22}$$

uniformly $\forall t > a$. Combining (16), (21) and (22) we have

$$\lim_{N\to\infty}|I| < \varepsilon \tag{23}$$

uniformly $\forall t > a$. Since ε is arbitrary it follows that

$$\lim_{N\to\infty}|I| = 0 \tag{24}$$

uniformly $\forall t > a$.

Theorem 4 (Inversion)

Let F(y) be the distributional Weber transformation of $f \in W'(I)$ defined by (9). Then for each $\phi(x) \in \mathcal{D}(I)$,

$$\lim_{N\to\infty}\left\langle\int_0^N \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}yF(y)\,dy, \phi(x)\right\rangle = \langle f(x), \phi(x)\rangle. \tag{25}$$

Proof

Assume that the support of $\phi(x)$ is contained in $[c,d]$, $d > c > a$. Then

$$\langle \int_0^N \frac{C_\nu(xy,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} yF(y)dy, \phi(x) \rangle$$

$$= \int_c^d \phi(x)dx \int_0^N y \frac{C_\nu(xy,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} F(y)dy \tag{26}$$

$$= \int_c^d \phi(x)dx \int_0^N \langle f(t), C_\nu(ty,ay)t \rangle \times y \frac{C_\nu(xy,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} dy \tag{27}$$

$$= \int_0^d \langle f(t), \int_0^N t \frac{C_\nu(xy,ay)C_\nu(ty,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} y\, dy \rangle \phi(x)dx \tag{28}$$

$$= \int_c^d \langle f(t), tW_N(t,x) \rangle \phi(x)dx \tag{29}$$

$$= \langle f(t), t \int_c^d xW_N(t,x) \frac{\phi(x)}{x} dx \rangle \tag{30}$$

$$= \langle f(t), t \frac{\phi(t)}{t} \rangle = \langle f(t), \phi(t) \rangle . \tag{31}$$

The equality of expressions (26) and (27) is justified by Theorems 2 and 3. That (27) and (28) are equal follows from Lemma 3. The equality of (29) and (30) can be established by the Riemann sums technique (Zemanian, 1968). Lastly, the expression (30) goes into (31) as $N \to \infty$ in view of Lemma 11. This completes the proof of the theorem.

Remark

The above inversion theorem has been established by interpreting convergence in the weak topology of $\mathcal{D}'(I)$ and cannot be proved in the weak topology of $W'(I)$. For if we define an infinitely differentiable function $\phi(x) \in W(I)$ such that

$$\phi(x) = \begin{cases} 0 & x < 1 \\ x^{3/2} & x > k > 2 \end{cases}$$

one can readily show that

$$\int_a^\infty \phi(x)dx \int_0^N \frac{C_\nu(xy,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} yF(y)dy$$

does not exist. Indeed

$$\int_a^\infty \phi(x)C_\nu(xy,ay)dx = \int_k^\infty x^{3/2}C_\nu(xy,ay)dx$$

which is divergent.

Theorem 5 (Uniqueness)

Let $f$ and $g \in W'(I)$ and let $F(\tau)$, $G(\tau)$ be Weber transforms of $f$ and $g$ respectively. If $F(\tau) = G(\tau)$ for all $\tau > 0$, then $f = g$ in the sense of equality in $\mathcal{D}'(I)$. The proof is trivial.

ILLUSTRATION OF THE INVERSION THEOREM BY MEANS OF A NUMERICAL EXAMPLE

Consider the delta functional $\delta(t-k)$, concentrated at a point $k$, $a < k < \infty$. Since $\delta(t-k) \in \mathcal{E}'(I)$, $I = (a,\infty)$, and $\mathcal{E}'(I)$ is a subspace of $W'(I)$. The Weber transform of $\delta(t-k)$ is given by

$$\left(W_\nu\delta(t-k)\right)(y) = \langle \delta(t-k), tC_\nu(ty,ay) \rangle = kC_\nu(ky,ay).$$

Now, by inversion theorem, for any $\phi(x) \in \mathcal{D}(I)$,

$$\langle \int_0^N \frac{C_\nu(xy,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} ykC_\nu(ky,ay)dy, \phi(x) \rangle$$

$$= k \int_a^\infty \int_0^N \frac{C_\nu(xy,ay)C_\nu(ky,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} y\, dy\, \phi(x)dx$$

$$= k \int_0^N \frac{C_\nu(ky,ay)}{J_\nu^2(ay) + Y_\nu^2(ay)} y\, dy \int_0^\infty C_\nu(xy,ay) \frac{x\phi(x)}{x} dx.$$

Since $\phi(x)$ is of compact support the change in order of integration is justified. Now letting $N \to \infty$ and using Theorem 1, we see that the last expression tends to $\frac{k\phi(x)}{k} = \phi(k) = \langle \delta(x-k), \phi(x) \rangle$. Thus the inversion theorem is illustrated.

AN OPERATIONAL CALCULUS

In this section, we shall apply the preceding theory in solving certain differential operator equations. Define the operator $\Delta_t^*: W'(I) \to W'(I)$ by the relation

$$\langle \Delta^*f(t), \phi(t) \rangle \triangleq \langle f(t), t\, \Delta_t \frac{\phi(t)}{t} \rangle$$

for all $f \in W'(I)$ and $\phi(t) \in W(I)$.

It can be readily seen that

$$\langle (\Delta^*)^k f(t), \phi(t) \rangle = \langle f(t), t\, \Delta_t^k \frac{\phi(t)}{t} \rangle$$

for each $k = 1,2,3, \ldots$ . In case $f$ is a regular distribution generated by an element of $\mathcal{D}(I)$, then

$$\Delta_t^* f = \Delta_t f.$$

It can be proved that

$$\langle (\Delta_t^*)^k f(t), tC_\nu(ty,ay) \rangle = \langle f(t), t(\Delta_t^k)t \frac{C_\nu(ty,ay)}{t} \rangle = (-1)^k (y^{2k}) \langle f(t), tC_\nu(ty,ay) \rangle .$$

Therefore

$$W_\nu[(\Delta_t^*)^k f(t)] = (-1)^k y^{2k} W_\nu[f(t)], \qquad (32)$$

where $W_\nu[f(t)]$ denotes the generalized $W_\nu$ transform of $f(t)$. Now we consider the operator equation

$$P(\Delta_x^*)u = g \qquad (33)$$

where $g \in W'(I)$ and P is any polynomial having no zeros on $-\infty < x \le 0$. We wish to find out a generalized function $u \in W'(I)$ satisfying the operator equation (33). Taking the generalized $W_\nu$ transform of both sides of (33) and using (32), we get

$$P[-y^2]U(y) = G$$

where U and G are generalized $W_\nu$ transforms of u(x) and g(x) respectively. So that if $P[-y^2] \neq 0$, we can apply the inversion for the distributional $W_\nu$ transform and for each $\phi \in \mathcal{D}(I)$, we get

$$\langle u,\phi\rangle = \left\langle \int_0^N \frac{G(y)}{P[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle, \qquad (34)$$

By Theorem 3 we know that

$$|G(y)| \le y^{2r-1} \quad \text{as} \quad y \to \infty$$

for some non-negative integer r depending upon g. Now let Q(x) be a polynomial of degree r+1 having no zeros on the negative real axis. Then, the convergence of the right-hand side of (34) can be established as below:

$$\left\langle \int_0^N \frac{G(y)}{P[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle$$

$$= \left\langle Q(\Delta_x) \int_0^N \frac{G(y)}{P[-y^2]Q[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle$$

$$= \left\langle \int_0^N \frac{G(y)}{P[-y^2]Q[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, Q(\Delta_x)\phi(x) \right\rangle$$

(by integration by parts).

Let us suppose that the support of $\phi(x)$ is contained in [A,B]. Then, we can find a constant L such that for $N_1,N_2 > L$ we have

$$|J| \equiv \left| \left\langle \int_{N_1}^{N_2} \frac{G(y)}{P[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle \right|$$

$$\le C \int_{N_1}^{N_2} \left| \frac{y^{2r}}{P[-y^2]Q[-y^2]} \right| dy \int_A^B \left| \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)} \right| |\phi(x)|\, dx.$$

Since for $x \in [A,B]$,

$$\left| \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)} \right| \le C_1$$

as $y \to \infty$, we can find a positive constant M such that

$$|J| \le CM \int_{N_1}^{N_2} \frac{y^{2r}}{P[-y^2]Q[-y^2]}\, dy \to 0$$

as $N_1,N_2 \to \infty$. Therefore

$$\lim_{N\to\infty} \left\langle \int_0^N \frac{G(y)}{P[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle$$

exists and by completeness of $\mathcal{D}'(I)$ there exists $f \in \mathcal{D}'(I)$ such that

$$\lim_{N\to\infty} \left\langle \int_0^N \frac{G(y)}{P[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle \qquad (35)$$

$$= \langle f,\phi \rangle .$$

Now for all $\phi \in \mathcal{D}(I)$, we have

$$\lim_{N\to\infty} \left\langle P(\Delta_x) \int_0^N \frac{G(y)}{P[-y^2]} \cdot \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(ay)}\, y\, dy, \phi(x) \right\rangle$$

$$= \langle P(\Delta_x)f,\phi \rangle$$

or

$$\lim_{N\to\infty} \left\langle \int_0^N G(y) \frac{C_\nu(xy,ay)}{J_\nu^2(ay)+Y_\nu^2(au)}\, y\, dy, \phi(x) \right\rangle$$

$$= \langle P(\Delta_x)f,\phi \rangle .$$

Hence, by our inversion Theorem 4, it follows that

$$\langle g,\phi \rangle = \langle P(\Delta_x)f,\phi \rangle .$$

This proves that f determined by (35), which belongs to $\mathcal{D}'(I)$ and is the restriction of $u \in W'(I)$, satisfies the operator equation (33).

## DIRICHLET'S PROBLEM IN CYLINDRICAL COORDINATES

Consider an infinite plate of thickness L with a transverse circular cylindrical hole of radius a and define a cylindrical coordinate system $(r,\theta,z)$ such that z is coincident with the axis of the hole.

For axial symmetry, the flow of heat is governed by the differential equation:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} = 0 \qquad (36)$$

where $T = T(r,z)$ is the temperature. We inforce the following generalized boundary conditions:

(i) $T(r,z)$ converges in $\mathcal{D}'(I)$, $I = (a,\infty)$ to some Weber transformable generalized function f(r) as $z \to 0+$.

(ii) $T(r,z)$ converges in $\mathcal{D}'(I)$, $I = (a,\infty)$ to some Weber transformable generalized function g(r)

as $z \to L$.

(iii) $T(r,z)$ converges to zero pointwise on $0 < z < L$ as $r \to a$.

(iv) $T(r,z)$ converges to zero pointwise on $0 < z < L$ as $r \to \infty$.

Applying the conventional Weber transform to (36) we get

$$-u^2\overline{T}(u,z) + \frac{\partial^2}{\partial z^2}\overline{T}(u,z) = 0 . \qquad (37)$$

Therefore

$$\overline{T} = Ae^{-uz} + Be^{uz}$$

where A and B are constants. As $z \to 0$, by condition (i) we can write

$$\overline{T} = A + B = \langle f(r), rC_0(ru,au)\rangle . \qquad (38)$$

As $z \to L$ by condition (ii) we can write

$$\overline{T} = Ae^{-uL} + Be^{uL} = \langle g(r), rC_0(ru,au)\rangle . \qquad (39)$$

Solving equations (38) and (39) we obtain

$$A = \frac{\langle f(r), rC_0(ru,au)\rangle - e^{-uL}\langle g(r), rC_0(ru,au)\rangle}{(1 - e^{-2uL})}$$

and

$$B = \frac{\langle f(r), rC_0(ru,au)\rangle - e^{-uL}\langle g(r), rC_0(ru,au)\rangle}{(1 - e^{2uL})}$$

Therefore the solution of equation (37) is given by

$$\overline{T}(u,z) = \frac{\langle f(r), rC_0(ru,au)\rangle - e^{-uL}\langle g(r), rC_0(ru,au)\rangle}{(1 - e^{-2uL})} e^{-uz} + \frac{\langle f(r), rC_0(ru,au)\rangle - e^{uL}\langle g(r), rC_0(ru,au)\rangle}{(1 - e^{2uL})} e^{uz}. \quad (40)$$

Applying the inverse Weber transform $W_\nu^{-1}$ to (40) we get

$$T(r,z) = \lim_{N\to\infty} \int_0^N \frac{uC_\nu(ru,au)\overline{T}(u,z)}{J_\nu^2(au) + Y_\nu^2(au)} du \qquad (41)$$

in $\mathcal{D}'(I)$, where $\overline{T}(u,z)$ is given by the right-hand side of (40).

Now, we have to show that $T(r,z)$ given by (41) satisfies the given boundary conditions and differential equation (36). By Theorem 3

$$|\langle f(r), rC_0(ru,au)\rangle| = O(u^{-|\nu|-\frac{1}{2}}), \quad u \to 0$$
$$= O(u^{2r-1}), \quad u \to \infty$$

and

$$|\langle g(r), rC_0(ru,au)\rangle| = O(u^{2r-1}), \quad u \to \infty$$
$$= O(u^{-|\nu|-\frac{1}{2}}), \quad u \to 0.$$

Therefore

$$\overline{T}(u,z) = O(u^{2r-1})\left[\frac{1}{1+e^{-uL}} e^{-uz} + \frac{1}{1+e^{uL}} e^{uz}\right], \quad u \to \infty \quad (42)$$

$$= O(u^{-|\nu|-\frac{1}{2}})\left[\frac{1}{1+e^{-uL}} e^{-uz} + \frac{1}{1+e^{uL}} e^{uz}\right], \quad u \to 0. \quad (43)$$

To verify the boundary conditions (i) and (ii) assume that $Q(x)$ is a polynomial of degree $r+2$ with no zero on the negative real axis. Then, for each $\phi \in \mathcal{D}(I)$ with support contained in $[a,b]$ we have

$$\langle T(r,z), \phi(r)\rangle$$
$$= \lim_{N\to\infty} \langle Q(\Delta_r) \int_0^N \frac{uC_\nu(ru,au)\overline{T}(uz)du}{[J_\nu^2(au)+Y_\nu^2(au)]Q(-u^2)}, \phi(r)\rangle$$
$$= \lim_{N\to\infty} \int_0^N \frac{u\overline{T}(u,z)du}{Q(-u^2)[J_\nu^2(au)+Y_\nu^2(au)]} \times$$
$$\times \int_c^b C_\nu(ru,au)Q(\Delta_r)\phi(r)dr \qquad (44)$$

(by integration by parts).

From (40) it can easily be shown that, when $z \to 0$

$$\overline{T}(u,z) = \langle f(r), rC_0(ru,au)\rangle \qquad (45)$$

and when $z \to L$

$$\overline{T}(u,z) = \langle g(r), rC_0(ru,au)\rangle . \qquad (46)$$

Now in view of the orders of $\overline{T}(u,z)$, the right-hand side of (44) converges uniformly with respect to $0 < z \le L$ as $N \to \infty$. Therefore, letting $z \to 0+$ and interchanging the limiting operations with respect to N and z in the right-hand side of (44), we get

$$\lim_{z\to 0+} \langle T(r,z), \phi(r)\rangle$$
$$= \lim_{N\to\infty} \int_a^b Q(\Delta_r)\phi(r)dr \frac{uC_\nu(ru,au)\overline{T}(u,z)}{[J_\nu^2(au)+Y_\nu^2(au)]Q(-u^2)} du$$
$$= \lim_{N\to\infty} \int_a^b \phi(r)dr \int_0^N u \frac{C_\nu(ru,au)}{J_\nu^2(au)+Y_\nu^2(au)} \overline{T}(u,z)du$$

(by integration by parts)

$$= \langle f, \phi\rangle \qquad \text{(by Theorem 4)}.$$

Similarly as $z \to \overline{L}$,

$$\lim_{z\to \overline{L}} \langle T(r,z), \phi(r) = \langle g, \phi\rangle$$

by using Theorem 4 and (46). Thus the boundary conditions (i) and (ii) are verified.

In view of the definition (1) of $C_\nu(ru,au)$ and the properties of $\overline{T}(u,z)$ given by (40) the verification of the boundary condition (iii) is trivial.

The boundary condition (iv) can be verified by using an analogue of the Riemann Lebesgue Lemma

(Watson, 1966) and the asymptotic orders (42) and (43) of $\bar{T}(u,z)$. Lastly, in view of the asymptotic orders of $\bar{T}(u,z)$ and the fact that $0 \le z < L$ it can be readily justified that

$$\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right) T(r,z)$$

$$= \lim_{N\to\infty} \int_0^N \frac{u}{J_\nu^2(au)+Y_\nu^2(au)} \times \left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right) C_\nu(ru,au)\bar{T}(u,z)\,du$$

$$= \lim_{N\to\infty} \int_0^N \frac{u(1-e^{-2uL})^{-1}\left[\langle f(t),tC_0(tu,au)\rangle - e^{-uL}\langle g(t),tC_0(tu,au)\rangle\right]}{J_\nu^2(au) + Y_\nu^2(au)} \times \left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right) e^{-uz} C_\nu(ru,au)\,du$$

$$+ \lim_{N\to\infty} \int_0^N \frac{u(1-e^{2uL})^{-1}\left[\langle f(t),tC_0(tu,au)\rangle - e^{uL}\langle g(t),tC_0(tu,au)\rangle\right]}{J_\nu^2(au) + Y_\nu^2(au)} \times \left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right) e^{uz} C_\nu(ru,au)\,du \;.$$

Therefore $T(r,z)$ as defined by (41) satisfies the differential equation (36).

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# Stratigraphic Palynology of the Castlereagh River Valley, New South Wales

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ABSTRACT. The palynology of some thirty-five shallow water bores in the Castlereagh River Valley is presented here. The palynology shows that the age of the basement to the groundwater system is Early Cretaceous around Gilgandra and downstream. Upstream of Gilgandra the basement age is mainly Triassic with one occurrence of the Jurassic and two late Permian assemblages.

The oldest assemblage in the overlying Cainozoic alluvium is mid-late Miocene. Younger Pliocene and Pleistocene assemblages were also found although most of the alluvium was barren.

## INTRODUCTION

The Water Resources Commission of New South Wales has sunk many bores in the Castlreagh Valley in its programme of exploration for ground water. Some thirty-five bores have yielded workable palynological assemblages and they are reported here. For purposes of water exploration, the interest is centred on the Tertiary alluvial valley fills. However, the older basement is unconsolidated or weathered so that lithologically it is little different to the alluvium and difficult to distinguish while drilling is in progress. Consequently, both the palynology of the Cainozoic and the older basement is included here.

The area under study here is situated on the south eastern edge of the Coonamble Embayment, one of the structural units of the Great Australian Basin. It appears that the edges of the Great Australian Basin are the least understood and are probably more complex than the basin centre. The area also straddles the probable subsurface limits of both the Triassic and Permian sediments (Hawke *et al.*, 1975). This study shows a basement of Early Cretaceous, mid-late Jurassic, mid Triassic and Late Permian. The oldest Tertiary deposition is middle-late Miocene. (See Fig. 1), and in this respect, the Castlreagh River Valley is very like that of the Namoi and Gwydir River Valleys (Martin, 1980).

## GEOLOGY

The uppermost member of the Great Australian Basin represented here is probably equivalent to the Bungil Formation which is much thicker in New South Wales than in the type section in Queensland. However, the overlying Wallumbilla Formation may be involved as well. Of the mid-late Jurassic units, it is likely that, on lithological evidence, the equivalent of the Purlawaugh Formation is represented here (Hawke *et al.*, 1975). The mid-late Triassic is probably equivalent to the Wainamatta Group of the Sydney Bowen Basin and the Late Permian equivalent to the "Upper Coal Measures". (Menzies, 1975; Branagan, 1969).

The bore logs show that the Cainozoic alluvium consists of gravel, sands and clays. The upper part is consistently brown, yellow, orange or reddish. There may be grey streaks or thin grey lenses, but these are very minor. At deeper levels, consistently grey clays are encountered. Most bores show one brown layer of sediment overlying one grey layer (see Fig. 2), but a few show two grey layers separated by an intervening brown layer. Only the consistently grey clays have yielded palynological assemblages. It appears that sediments which are predominantly brown or varicoloured with only minor grey streaks are still too oxidised to yield pollen.

## PALYNOSTRATIGRAPHY

(1) Late Permian. Two samples of this age are recorded here. One of them has a particularly rich flora in which spores predominate. *Leiotriletes directus* is particularly abundant together with a form which looks like this species but has some contents within the spore. *Dulhuntyspora parvitholus* and *Didecitriletes ericanus* which range from Upper Stage 5 through the *Protohaploxypinus reticalatus* Assemblage are both present. No species which first appear in the *P. reticulatus* Assemblage have been found. *Alisporites australis*, although present, is not prominent (see Appendix). These features indicate Upper Stage 5 rather than the *P. reticulatus* Assemblage. (Helby 1973; Kemp *et al.*, 1977).

(2) Triassic. *Alisporites australis* and *Aratisporites* spp. clearly mark these assemblages as Triassic. Preservation is generally poor, but a few samples showing better preservation allow some specific identifications. The larger species of *Aratisporites* are present, viz., *A. parvispinosus*, *A. flexibilis* and *A. banksii* which indicate the mid Triassic *Aratisporites parvispinosus* Assemblage (Helby 1973). *Nevesisporites limulatus*, *Polypodiisporites mutabilis*, *Neoraistrickia taylori* and *Uvaesporites verrucosus* are also present (see Appendix). An occasional specimen of *Protohaploxypinus* is seen, but species of *Lunatisporites* have not been found. It is assumed that the poorly preserved assemblages are of the same age.

(3) Jurassic. Only one poorly preserved assemblage has been found. *Tsugaepollenites* spp.

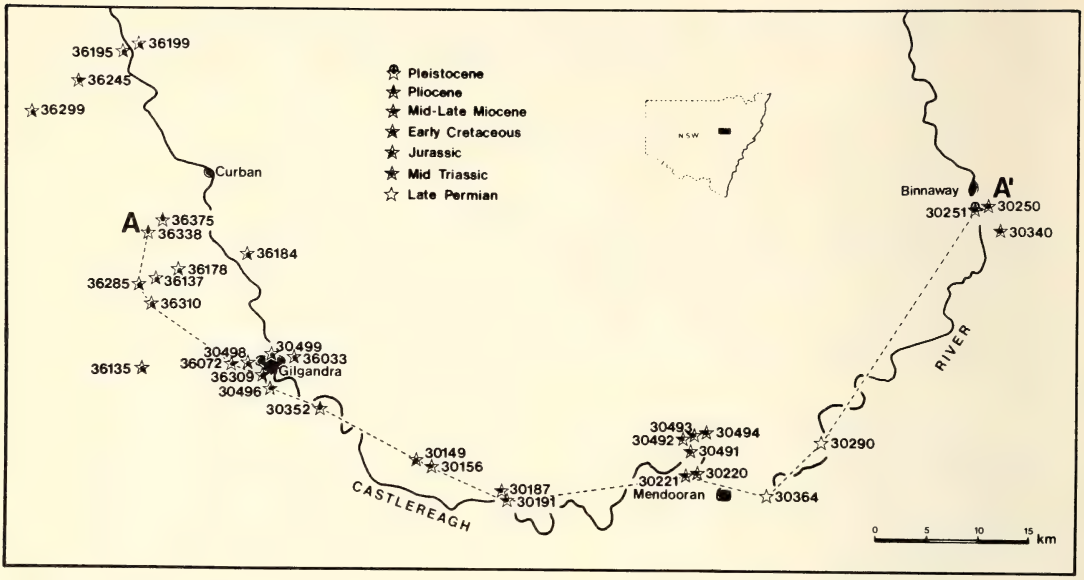


Fig. 1 Locality map showing bore sites and the ages of the palynological assemblages encountered in them.

is the most common, with *Araucariacites australis* and *Lycopodiumsporites* spp. prominent also. Bisaccates, e.g., *Alisporites* sp., and the spores *Baculatisporites comaumensis*, *Neoraistrickia* sp., *Cingulatisporites suaevus* and cf *Reticulatisporites pudens* are present also (see Appendix). These characteristics indicate the mid-late Jurassic *Tsugaepollenites dampierei* Assemblage (Balme 1964; 1957).

(4) Early Cretaceous. In these assemblages, *Baculatisporites comaumensis*, *Podocarpidites* sp. and *Lycopodiumsporites* spp. are common. Many other species are present, and those found in three representative samples are listed in the Appendix. The diagnostic species *Murospora florida*, *Dictyotosporites speciosus*, *D. filosus* and *Aquitriradites hispidus* indicate either the *Crybelosporites stylosus* or *Dictyotosporites speciosus* Zones, both of Neocomian-Aptian age (Dettmann and Palyford, 1969). Most of the early Cretaceous assemblages are well preserved when compared with those of the Triassic and Jurassic.

(5) Cainozoic

a. Mid-late Miocene. The diagnostic species *Polypodiaceoisporites tumulatus*, *Rugulatisporites micraulaxis*, *Symplocoipollenites austellus* and *Triporopollenites bellus* clearly indicate the *T. bellus* Zone of mid-late Miocene age (Stover and Partridge, 1973). Only two species of the *Nothofagus* group, are present and together they account for some 10-20% of the total count. The *brassii* pollen type *N. emarcida* is well represented. The content of the Myrtaceae group may be quite high, up to 40%, but is is very variable and one assemblage has only 2%. See Appendix.

b. Pliocene. These assemblages lack the *brassii* pollen type of *Nothofagus* (the 0.8% of *N. emarcida* is significant and could result from reworking, contamination, etc. (See Appendix). This feature, together with the relatively low frequencies of *Tubulifloridites* spp. and *Graminidites media* are typical of the Pliocene (Martin 1973; 1979). Two of the assemblages in the Appendix fit the Myrtaceae phase. The third (Bore 36338, at 87-88m) has a relatively small amount of *Nothofagus aspera* and a higher content of gymnosperms which are characteristics of the *Nothofagus* phase. The Myrtaceae phase occurs both above and below the *Nothofagus* phase. The latter is always very restricted in thickness and is thus a good marker horizon.

c. Pleistocene. The one assemblage of this age has a high content of compositae (= *Tulifloridites* spp. in the Appendix) and this feature distinguishes it from the Pliocene (Martin 1979). Usually, Gramineae (= *Graminidites media*) is also abundant in Pleistocene assemblages, but it is unusually low here. The restricted diversity of this assemblage is typical of that of the Pleistocene.

(6) No dinoflagellates are present except for a few of the psilate, freshwater forms in one of the mid-late Miocene assemblages. Their absence indicates fresh water deposition.

DISCUSSION

The oldest Tertiary deposition in the Castlereagh Valley is mid-late Miocene. In this respect, it resembles the Namoi and Gwydir River

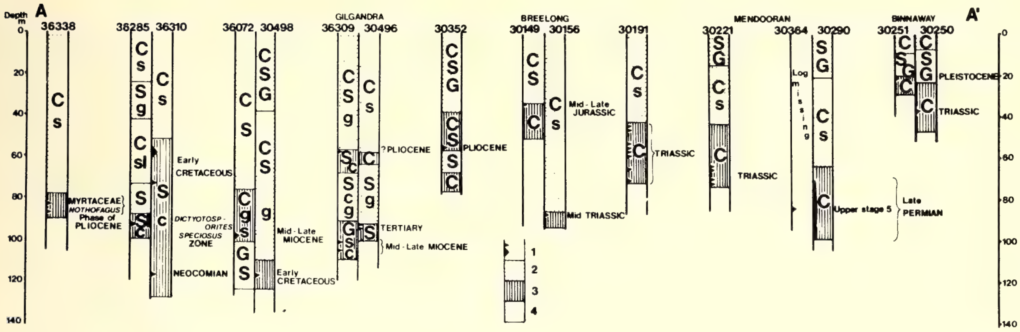

Fig. 2 Cross section A-A[1] (see Fig. 1). C, clay; S, sand; G, gravel. Capital letters indicate a major constituent of the sediments, lower case, a minor constituent.

1, Palynological assemblage. 2, Predominently brown, yellow, orange or red sediments. 3, Consistently grey coloured sediments. 4, Sand and gravel, the only colour being that of the rock particles present.

Valleys where mid-late Miocene deposition directly overlies the basement, indicating conclusively that Tertiary deposition started at that time. (Martin, 1980). While Tertiary and basement assemblages have not been encountered in the same bore in the Castlereagh Valley, it is likely that Tertiary deposition started in the mid-late Miocene here also.

The mid-late Miocene assemblages show a patchy distribution around Gilgandra and further downstream (see Fig. 1). The Pliocene has a similar distribution except for one assemblage near Mendooran which has a mixture of Pliocene and Triassic. The Pliocene is encountered in the upper grey clay layer in those bores showing two of these layers. There is one Pleistocene assemblage at Binnaway.

The basement is Early Cretaceous around Gilgandra and downstream. Upstream of Gilgandra, the basement is mostly mid Triassic with one occurrence of the mid-late Jurassic, and east of Mendooran, two occurrences of the Late Permian.

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TABLE 1

THE OCCURRENCE OF THE PALYNOLOGICAL ZONES

Where the evidence is not entirely conclusive, the age rather than the palynological zone is given.

| Bore | Depth (m) | Palynological Zone or Age |
|---|---|---|
| 36199 - | 109-110 | *Crybelosporites stylosus* Zone, Early Cretaceous |
| | 111-112<br>118-119 | Early Cretaceous |
| 36195 - | 86.7-88 | Early Cretaceous |
| 36245 - | 104-104.1 | *T. bellus* Zone, mid-late Miocene |
| 36299 - | 94-98 | *Dictyotosporites speciosus* Zone |
| | 102-104<br>106-109<br>112-114 | Early Cretaceous |
| Curban - Kamber area | | |
| 36375 - | 60-62 | Pliocene, Myrtaceae phase |
| 36338 - | 83-84 | Pliocene, Myrtaceae phase |
| | 87-88 | Pliocene, weak *Nothofagus* phase |
| 36184 - | 132-133 | Very little pollen, probably Early Cretaceous |
| 36178 - | 114.3-115.8 | Early Cretaceous |
| 36194 - | 88.7-91<br>91-93 | Very little pollen, mixed Tertiary and Cretaceous |
| 36285 | 94-96 | *Dictyotosporites speciosus* Zone, Early Cretaceous |
| 36137 - | 116-118<br>140-143 | Very little pollen, Early Cretaceous |
| 36310 - | 56-60<br>72-73<br>116-118 | Early Cretaceous<br>A Neocomian indicator species present here |
| Gilgandra district | | |
| 36135 - | 48-55 | *Dictyotosporites speciosus* Zone, Early Cretaceous |
| 36072 - | 96-100 | *T. bellus* Zone - Mid-late Miocene |
| 30498 - | 117.6-117.9 | Early Cretaceous |
| Gilgandra district (Cont.) | | |
| 36309 - | 57-58 | Very little pollen, probably Pliocene |
| | 91.5-92<br>101<br>104.5-105 | *T. bellus* Zone |
| 30496 - | 93-94<br>94-96 | Very little pollen, a few Tertiary forms |
| 30499 - | 80.2-83<br>119<br>119-120 | Early Cretaceous |
| | 120-121.1 | ? Early Cretaceous |
| 36033 - | 48.5 | Early Cretaceous |
| 30352 - | 54.2-56.4 | Pliocene |
| Breelong | | |
| 30149 - | 34.1 | Mid-late Jurassic |
| 30156 - | 86.5-89 | Mid-late Triassic |
| 30189 - | 50 | Triassic, most likely *Aratisporites parvispinosus* Zone, mid Triassic |
| 30191 - | 44-47<br>53.5<br>65.5-67<br>71-73 | Pollen very poorly preserved, Triassic |
| Mendooran | | |
| 30492 - | 82-84 | *Aratisporites parvispinosus* Zone, mid Triassic |
| 30491 - | 71-72 | Mixed Pliocene and mid-late Triassic |
| | 73-75<br>77 | Poor preservation, Triassic |
| 30493 - | 54 | Mid-late Triassic |
| 30494 - | 38 | Mid Triassic |
| 30221 - | 64-67<br>70-73 | Very little pollen, Triassic |
| 30220 - | 71.5-73 | Very little pollen, Triassic |

TABLE 1 (Cont.)

| Bore | Depth (m) | Palynological Zone or Age | Bore | Depth (m) | Palynological Zone or Age |
|---|---|---|---|---|---|
| Mendooran (Cont.) | | | Binnaway | | |
| 30364 | 84-85 | Upper Stage 5 of the Late Permian | 30251 | 20.5-21.4 | Pleistocene |
| 30290 | 71.5-99.5 | Permian, probably Stage 5 | 30250 | 36.7-38.4 | Triassic |
| | | | 30340 | 25-26.2<br>33.5-36 | Mid Triassic |

## APPENDIX

### A PERMIAN ASSEMBLAGE

Bore 30364, 84-85m.

*Alisporites australis*
*Bacanisporites undosus* Balme & Hennelly 1956
*Baculatisporites comaumensis* (Cookson) Potonié 1956
*Barakarites rotatus* (Balme & Hennelly) Bharadwaj & Tiwari 1964
*Circulisporites parvus* de Jersey 1962
*Cycadopites follicularis* Wilson & Webster 1946
*Cyathidites australis* Couper 1953
*Didecitriletes ericanus* (Balme & Hennelly) Venkatachala & Kar 1965
* *Granulatisporites trisinus* Balme & Hennelly 1956
** *Leiotriletes directus* Balme & Hennelly 1956
* *Lunbladispora iphilegna* Foster 1979
*Maculatisporites gondwanensis* Tiwari 1965
*Microbaculispora tentula* Tiwari 1965
*Peltacystia venosus* Balme & Segroves 1966
*Protohaploxypinus limpidus* (Balme & Hennelly) Balme & Playford 1967
*P. microcorpus* (Schaarschmidt) Clarke 1965
*Retrusotriletes nigritellus* (Luber) Foster 1979
*Striatoabieites multistriatus* (Balme & Hennelly) Hart 1964
*Vitreisporites signatus* Leschik 1955

### A TRIASSIC ASSEMBLAGE

Bore 30187, 50m.

*Acanthotriletes bradiensis* Playford 1965
*Alisporites australis* de Jersey 1962
*Anapiculatisporites* cf. *A. cooksoneae* Playford 1965
*Aratisporites flexibilis* Playford & Dettman 1965
*A. parvispinosus* Leschik emend Plaford 1965
*Baculatisporites comaumensis* (Cookson) Potonié 1956
*Biretisporites* sp.
*Calamospora mesozoica* Couper 1958
*Cyadopites follicularis* Wilson & Webster 1946
*Dictyophyllidites mortonii* (de Jersey) Playford & Dettman 1965
*Neoraistrickia taylori* Playford & Dettmann 1965
*Osmundacidites* cf. *O. wellmanii* Couper 1953
*Polypodiisporites mutabilis* Balme 1970
*Vitreisporites signatus* Leschik 1955

* Common

** The most common

### EARLY CRETACEOUS ASSEMBLAGES

| *Alisporites grandis* (Cookson) Dettmann | Bore<br>Depth(m) | 36310<br>72-73 | 36310<br>116-118 | 36285<br>94-96 |
|---|---|---|---|---|
| *Alisporites grandis* (Cookson) Dettmann 1963 | | + | | + |
| *A. similis* (Balme) Dettmann 1963 | | + | + | |
| *Baculatisporites comaumensis* (Cookson) Potonié 1956 | | + | + | + |
| *Ceratosporites equalis* Cookson & Dettmann 1958 | | | + | |
| *Classopollis* cf. *C. classoides* Pflug emend Dettman 1963 | | + | + | + |
| *Contignisporites glebulentus* Dettmann 1963 | | | + | |
| *Crybelosporites* cf. *C. striatus* (Cookson & Dettmann) Dettmann 1963 | | | | + |
| *Cyathidites australis* Couper 1953 | | + | + | |
| *C. minor* Couper 1953 | | + | + | |
| *Dictyophyllidites crenatus* Dettmann 1963 | | | | + |
| *Dictyotosporites filosus* Dettmann 1963 | | + | | |
| *D. speciosus* Cookson & Dettmann 1958 | | | | + |
| *Foraminisporis dailyi* (Cookson & Dettmann) Dettmann 1963 | | + | | + |
| *Foveosporites canalis* Balme 1957 | | | + | |
| *Ginkgocycadophytus nitidus* (Balme) de Jersey 1962 | | + | | |
| *Klukisporites scaberis* (Cookson & Dettmann) Dettmann 1963 | | | + | |
| *Leptolepidites major* Couper 1958 | | | + | |
| *Lycopodiacidites asperatus* Dettmann 1963 | | + | + | |
| *Lycopodiumsporites austroclavatidites* (Cookson) Potonié 1956 | | + | + | + |
| *L. eminulus* Dettmann 1963 | | + | | |

EARLY CRETACEOUS ASSEMBLAGES (Cont.)

| Bore<br>Depth (m) | 36310<br>72-73 | 36310<br>116-118 | 36285<br>94-96 |
|---|---|---|---|
| *L. nodosus* Dettmann 1963 | + | + | |
| *Microcachryidites antarcticus* Cookson 1947 | + | + | |
| *Murospora florida* (Balme) Pocock 1961 | | + | |
| *Neoraistrickia truncatus* (Cookson) Potonié 1956 | | | + |
| *Osmundacidites wellmanii* Couper 1953 | + | + | |
| *Podocarpidites* sp. | + | + | + |
| *Reticulatisporites pudens* Balme 1957 | + | | |
| *Stereisporites antiquasporites* (Wilson & Webster) Dettmann 1963 | | | + |
| *Tsuggaepollenites* spp. | | + | |

MID-LATE MIOCENE ASSEMBLAGES

| Bore<br>Depth (m) | 36245<br>104-104.1<br>% | 36309<br>101<br>% | 36309<br>104-104.5<br>% |
|---|---|---|---|
| SPORES | | | |
| *Baculatisporites disconformis* Stover 1973 | | | 0.9 |
| *Cyathea paleospora* Martin 1973 | 4.3 | 4.4 | 17.6 |
| *Cyathidites subtilis* Partridge 1973 | 3.5 | 7.7 | 2.8 |
| *Deltoidospora incospicua* Martin 1973 | | 1.1 | 4.6 |
| *Gleichenia circinidites* Cookson 1953 | | | 1.8 |
| *Laevigatosporites ovatus* Wilson & Webster 1946 | 1.7 | 2.2 | 6.4 |
| *Matonisporites ornamentalis* (Cookson) Partridge 1973 | + | 7.7 | 4.6 |
| *Polypodiaceoisporites tumulatus* Partridge 1973 | + | | 0.9 |
| *Reticuloidosporites minisporis* Martin 1973 | 0.9 | | |
| *Rugulatisporites mallatus* Stover 1973 | | | 1.8 |
| *R. micraulaxis* Partridge 1973 | | | 0.9 |
| *Sphagnum* sp. | | | 0.9 |
| GYMNOSPERM POLLEN | | | |
| *Araucariacites australis* Cookson 1947 | 4.3 | 4.4 | |
| Cupressaceae sp. indet | 0.9 | | |
| *Podocarpus (=Dacrycarpites) asutraliensis* (Cookson & Pike) Martin 1973 | 2.6 | 3.3 | 2.8 |
| *Podocarpus elliptica* (Cookson) Martin 1973 | 0.9 | 5.5 | 7.4 |
| *Trisaccites micropterus* Cookson & Pike 1954 | | 1.1 | 0.9 |
| ANGIOSPERM POLLEN | | | |
| *Acacia myriosporites* Cookson 1954 | + | | |
| *Casuarina (Haloragacidites harrisii* (Couper) Harris 1971 + *Casuarinidites cainozoicus* Cookson & Pike 1954) | 3.5 | 6.6 | 4.6 |
| *Cupaneidites orthoteichus* Cookson & Pike 1954 | 0.9 | 1.1 | |
| *Drimys tetradites* Martin 1973 | | | 1.8 |
| *Micrantheum spinyspora* Martin 1973 | | 1.1 | |
| *Milfordia hypolaenoides* Erdtman 1960 | | 1.1 | |
| *Myrtaceae* sp. indet | 11.4 | | 5.5 |
| *Myrtaceidites eucalyptoides* Cookson & Pike 1954 | 2.6 | 1.1 | |
| *M. mesonesus* Cookson & Pike 1954 | 0.9 | | |
| *M. parvus* Cookson & Pike 1954 | 25.4 | 1.1 | 0.9 |
| *Nothofagus aspera* Cookson 1959 | 1.7 | 12.0 | 3.7 |
| *N. emarcida* Cookson 1959 | 9.6 | 8.8 | 14.8 |
| *Proteacidites ivanhoensis* Martin 1973 | 0.9 | 2.2 | |
| *P. subscabratus* Couper 1960 | | 3.3 | 0.9 |
| *Quintinia psilatispora* Martin 1973 | 0.9 | 1.1 | |
| *Symplocoipollenites austellus* Partridge 1973 | 1.7 | | 0.9 |
| *Tricolpites psilatus* Martin 1973 | | 1.1 | |
| *Tricolporites microreticulatus* Harris 1965 | | 2.2 | 0.9 |
| *Tricolporopollenites cooksonii* Martin 1973 | | | 0.9 |
| *T. endobalteus* McIntyre 1965 | 3.5 | 3.3 | |
| *T. ivanhoensis* Martin 1973 | | | 0.9 |
| *Triporopollenites bellus* Partridge 1973 | 3.5 | | |
| Unknown types | 14.0 | 17.6 | 7.6 |

PLIOCENE ASSEMBLAGES

| Bore | 36338 | 36338 | 30352 |
|---|---|---|---|
| Depth (m) | 83-84 | 87-88 | 54.2-56.4 |
| | % | % | % |
| SPORES | | | |
| *Baculatisporites disconformis* Stover 1973 | 0.9 | | |
| *Cyathea paleospora* Martin 1973 | 22.3 | 4.0 | 8.6 |
| *Cyatheacidites annulatus* Cookson 1947 | | 0.8 | |
| *Cyathidites subtilis* Partridge 1973 | 2.5 | 1.6 | |
| *Deltoidospora granulomargo* Martin 1973 | 2.5 | | 0.8 |
| *D. inconspicua* Martin 1973 | 1.6 | 1.6 | 0.8 |
| *Dicksonia* sp. | | | 1.9 |
| *Gleichenia circinidites* Cookson 1953 | | 3.2 | |
| *Klukisporites lachlanensis* Martin 1973 | 3.3 | | |
| *Laevigatosporites ovatus* Wilson & Webster 1946 | | 8.0 | |
| *Polypodiaceoisporites tumulatus* Partridge 1973 | 0.9 | | |
| *Polypodiidites* sp. | + | | |
| GYMNOSPERM POLLEN | | | |
| *Araucariacites australis* Cookson 1947 | 4.1 | 4.8 | 13.3 |
| Cupressaceae sp. indet | | 1.6 | |
| *Dacrydium florinii* (Cookson & Pike) Cookson 1956 | 0.9 | 0.8 | |
| *Phyllocladidites palaeogenicus* Cookson & Pike 1954 | | 7.2 | |
| *Podocarpus (=Dacrycarpites) australiensis* (Cookson & Pike) Martin 1973 | 1.6 | 0.8 | |
| *Podocarpus elliptica* (Cookson) Martin 1973 | 9.1 | 12.9 | 2.8 |
| ANGIOSPERM POLLEN | | | |
| *Acacia myriosporites* Cookson 1954 | | 1.6 | |
| *Banksieaeidites elongatus* Cookson 1950 | 0.9 | | |
| *Casuarina (Haloragacidites harrisii* (Couper) Harris 1971 + *Casuarinidites cainozoicus* Cookson & Pike 1954) | 5.8 | 6.4 | 22.8 |
| Cyperaceae sp. indet | | 2.4 | |
| *Dodonaea sphaerica* Martin 1973 | | | 0.8 |
| *Drimys tetradites* Martin 1973 | 1.6 | 1.6 | 0.8 |
| *Graminidites media* Cookson 1947 | | 1.6 | 2.8 |
| *Haloragacidites haloragoides* Cookson & Pike 1954 | | 1.6 | 2.8 |
| Loranthaceae sp. indet | | | 0.8 |
| Malvaceae sp. indet | | 0.8 | |
| *Micrantheum spinyspora* Martin 1973 | | 0.8 | |
| *Milfordia hypolaenoides* Erdtman 1960 | 0.9 | | |
| Myrtaceae sp. indet | 14.9 | 4.8 | 9.5 |
| *Myrtaceidites eucalyptoides* Cookson & Pike 1954 | 4.1 | 1.6 | 7.6 |
| *M. mesonesus* Cookson & Pike 1954 | | | 4.8 |
| *M. parvus* Cookson & Pike 1954 | 7.4 | 2.4 | 3.8 |
| *Nothofagus aspera* Cookson 1959 | 0.8 | 6.4 | |
| *N. emarcida* Cookson 1959 | | | 0.8 |
| *Polygonum* sp. | | 0.8 | |
| *Proteacidites* sp. indet | 0.9 | | 0.8 |
| *Proteacidites ivanhoensis* Martin 1973 | 0.9 | | |
| *P. subscabratus* Couper 1960 | | 1.6 | |
| *P. symphyonemoides* Cookson 1950 | 0.9 | | |
| *Quintinia psilatispora* Martin 1973 | 0.9 | | |
| *Symplocoipollenites austellus* Partridge 1973 | | 2.4 | |
| *Stephanocolpites oblatus* Martin 1973 | | 0.8 | |
| *Tubulifloridites* spp. | | 0.8 | 2.8 |
| Unknown pollen types | 10.7 | 13.7 | 9.5 |

A PLEISTOCENE ASSEMBLAGE

| | Bore 30251 20.5-21.4m % |
|---|---|
| SPORES | |
| *Cingulatisporites bifurcatus* (Couper) Martin 1973 | 1.9 |
| *Cyathea paleospora* Martin 1973 | 14.1 |
| *Deltoidospora inconspicua* Martin 1973 | 1.9 |
| *Gleichenia circinidites* Cookson 1953 | 0.9 |
| *Laevigatosporites ovatus* Wilson & Webster 1946 | 1.9 |
| Osmundaceae sp. 2 in Martin 1973 | 0.9 |
| *Reticulatisporites cowrensis* Martin 1973 | 0.9 |
| *R. echinatus* Martin 1973 | 0.9 |
| GYMNOSPERM POLLEN | |
| *Araucariacites australis* Cookson 1947 | 1.9 |
| *Podocaarpus elliptica* (Cookson) Martin 1973 | 2.8 |
| ANGIOSPERM POLLEN | |
| *Acacia myriosporites* Cookson 1954 | 0.9 |
| *Casuarina (Haloragacidites harrisii* (Couper) Harris 1971 + *Casuarinidites cainozoicus* Cookson & Pike 1954 | 6.4 |
| *Graminidites media* Cookson 1947 | 2.8 |
| *Haloragacidites haloragoides* Cookson & Pike 1954 | 3.7 |
| Myrtaceae sp. indet | 29.2 |
| *Myrtaceidites mesonesus* Cookson & Pike 1954 | 0.9 |
| *Polyporina chenopodiaceoides* Martin 1973 | 2.8 |
| *Proteacidites* sp. indet | 0.9 |
| *Tubulifloridites* spp. | 19.8 |
| Unknown pollen types | 3.8 |

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# Conversion of Map Grid-References from the Yard to Metre Systems

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ABSTRACT. A simple procedure is set out for the conversion of map grid-references of locations in eastern New South Wales from the superseded Australian Survey Grid expressed in yards, used on the discontinued series of one inch to one mile "military" maps, to the Australian Map Grid expressed in metres. The procedure is intended for scientific use, with internal standard error of ±50 metres and is not intended for surveying purposes.

## INTRODUCTION

For many years virtually the sole source of contoured topographical maps of Australia was the Royal Australian Survey Corps of the Australian Army. In the early 1930s the Survey Corps adopted the transverse mercator projection for plotting their maps and overlaid on each a rectangular grid with lines spaced one thousand yards apart. The majority of the maps so produced were at a scale of one inch equals one mile, equivalent to a scale ratio of 1:63,360, and became generally referred to as "army", "military" or "one-inch-to-the-mile" maps. They covered half a degree of longitude and a quarter of a degree of latitude.

These maps were invaluable and were widely used for recording and analysis of field research data in geomorphology, geology, botany, forestry and archaeology. In New South Wales about 110, or one-sixth of the possible total number of maps, were produced. The majority covered the coastal belt and others the larger inland towns and their surroundings.

Production of the maps ceased in the late 1950s and a totally new scheme of cartography was adopted by the Australian National Mapping Council. Initially, the publication scales were altered to multiples of 1:25,000, the old yard grid continuing to be shown. In the mid 1960s, when the geodetic survey of the Australian continent had at last been completed and analysed, a new shape of the earth, or spheroid, was introduced for mapping. Also, the reference-grid overlay was changed to the Universal Transverse Mercator system scaled in thousands of metres and organised differently from the old yard grid. The version employed on Australian maps is called the Australian Map Grid.

The complete change of cartographic systems had the result that the large number of published locations employing the former yard grid system is meaningless in relation to present-day maps. The purpose of this paper is to provide a simple method for converting scientific grid-references in the old yard system directly into the current metre system with sufficient precision to recover the location intended by its recorder. (To achieve conversion to the level of precision required by surveyors is a more difficult problem and would possibly be treated by an adaptation of the method of Lauf (1961).) The alternative procedure - first locating the site on a one-inch map and scaling its position to a modern map using common surrounding features - assumes the availability of the necessary one-inch map. This would now depend on access to a library collection and could in general only be executed in the office.

## PRINCIPAL CHARACTERISTICS OF THE YARD AND METRE GRID SYSTEMS IN N.S.W.

The Australian Survey Grid (ASG) lines on the military maps were spaced at one-thousand yard intervals and had a common origin 400,000 yards west and 800,000 yards south of the intersection of the 34th parallel of latitude with a meridian which was central to a north-south "zone" five degrees of longitude wide. Most of the published one-inch maps for New South Wales covered areas within the zone numbered 8, a much smaller number fell within zone 7 west of longitude 148.5 deg. E. (roughly, a line through Dubbo and Mount Kosciusko). The grid systems in the two zones were totally separate and identically graduated.

The Australian Map Grid (AMG) employs zones six degrees wide, each with an origin of co-ordinates 500 000 metres west and 10 000 000 metres south of the intersection of the central meridian with the equator. The central and eastern portions of New South Wales are included in zones 55 and 56 separated by longitude 150°E. (Boggabri to Bega).

The effect of the change of spheroid on which positions are calculated was to shift the meridians slightly east and the parallels slightly south compared to their former positions. The amount of shift was variable, being greater in the south-eastern part of the State than in the north-eastern part.

Two cautionary remarks are in order at this point:

1. Another metric grid will be found indicated marginally on some New South Wales maps. This is the Integrated Survey Grid, and is intended for land-tenure registration. Under no circumstances should it be used for scientific purposes. The appearance of its grid values is closely but deceptively similar to those of the normal metric grid.

2. Commonwealth maps show a two-letter system for identifying the 100-km square within which a point lies. These letters are not arranged in an easily memorable system and are not shown on State maps. It is strongly urged they not be used, rather the name and number of the map should be stated when giving a grid reference.

## THE METHOD OF CONVERSION

The differences between the yard and metre grid systems include:

- . different units of measurement;
- . different central meridians of zones;
- . different zone-widths, the resultant distortions of scale being unrelated in any given area;
- . different origins for counting co-ordinates;
- . different grid orientations, the angular divergence changing significantly in both north-south and east-west directions;
- . different reference spheroids and therefore meridians and parallels shifted by an amount that varies from place to place.

A variety of conversion procedures was investigated in relation to the two principal criteria of simplicity of use and retention of the original precision of the published reference. The method described below emerged as best satisfying those criteria. The theoretical basis of the method is set out in the final section of this paper.

Since a single procedure applicable to the whole of New South Wales was unattainable the unit working area was fixed as the 1:250,000-scale standard mapping quadrangle, 1 degree north-south by 1½ degrees east-west. Within that area the variables listed above are just sufficiently controlled to retain the desired precision.

The steps involved in the procedure are:-

Step 1. Identify the 1:250,000 quadrangle, and the one-inch map if not already stated by the author.

Step 2. Using the information in the Table, restore to the yard grid eastings and northings the prefixes omitted as normal procedure.

Step 3. Subtract from the site co-ordinates the co-ordinates of the working origin supplied in the Table.

Step 4. Insert the residues, designated $dE_Y$ and $dN_Y$, respectively, into the conversion formulas supplied, obtaining metre-grid increments $dE_M$ and $dN_M$ (to the nearest whole number - no significance should be attached to decimals).

Step 5. Add to the last-named the metre-grid working origin supplied in the Table.

Step 6. Delete any prefixed digits to leave three-digit eastings and northings.

The working units throughout are one hundred yards and one hundred metres, being the best precision of grid interpretation attainable on normal one-inch maps. Extensive testing suggests that the conversion itself will have a standard error averaging ±50 metres. Taking into account the standard error of the original grid reference, rarely better than about ±100 yards (depending on the accuracy of the map and the care of its interpreter) this suggests that the standard error of the converted result may be conservatively taken as ±200 metres. To achieve better would almost certainly require a field visit to identify local features; more precise arithmetrical procedures would of themselves yield little improvement.

In the Table are set out for each 1:250,000 map area the necessary conversion data together with the ranges of the yard grids on all the one-inch maps known to have been published falling within that area. The area covered by the Table represents the eastern half of New South Wales. This is the area in which most field scientific investigations were carried out in the past where the degree of detail demanded the use of grid-references. The principles elaborated can be equally well applied to the western half of the State and the author is willing to provide conversion details should there be any need.

## EXAMPLES OF APPLICATION OF THE PROCEDURE

A. Stevens (1951, this Journal, Vol. 84, p.47) gives a grid reference 801472 on either the Cowra or Canowindra one-inch maps. The steps outlined previously then follow:

1. Using the Table or general knowledge identify the BATHURST 1:250,000 quadrangle.

2. By inspection of the grid ranges listed for Cowra and Canowindra maps identify the reference as pertaining to the Canowindra map.

| | | | | |
|---|---|---|---|---|
| | Grid reference $E_Y$, $N_Y$: | 801 | 472 | Y |
| | Full references ( prefixes from Table): | 1801 | 8472 | Y |
| 3. | Subtract the yard working origin: | 1400 | 7900 | Y |
| | Residues $dE_Y$, $dN_Y$ = | 401 | 572 | Y |
| 4. | From the formulae listed for BATHURST, increments $dE_M$, $dN_M$ = | 400 | 516 | M |
| 5. | Add metre working origin | 6300 | 62300 | M |
| | Results | 6700 | 62816 | M |
| 6. | Delete prefixes to obtain standard short form grid-references $E_M$, $N_M$ | 700 | 816 | M |

B. Retallack et al. (1977, Proc. Linn. Soc. N.S.W., vol. 101, p.79) give a grid reference 808877 on the Nymboida 1:63,360 map.

Steps:

| | | | |
|---|---|---|---|
| 1. | GRAFTON 1:250,000 quadrangle. | | |
| 2. | Grid reference $E_Y$, $N_Y$ | 808 | 877 Y |
| | Full grid reference | 5808 | 12877 Y |
| 3. | Subtract yard working origin | 4500 | 12800 Y |
| | Residues $dE_Y$, $dN_Y$ = | 1308 | 77 Y |
| 4. | From the formulae listed for GRAFTON, increments $dE_M$, $dN_M$ = | 1221 | 48 M |
| 5. | Add metre working origin | 3500 | 66800 M |
| | Results | 4721 | 66848 M |
| 6. | Standard format of grid reference $E_M$, $N_M$ | 721 | 848 M |

C. Locality stated to be on BEGA 1:250,000 map, grid reference 242.9; 531.9.

Steps:

| | | | |
|---|---|---|---|
| 1. | Because the reference was obtained from a 1:250,000 scale map, in the absence of 1:63,630 maps, the units are thousands of yards. | | |
| 2. | Grid reference in thousands of yards | 242.9 | 531.9 |
| | Grid reference including prefixes and converted to hundreds of yards | 2429 | 5319 Y |
| 3. | Subtract the yard working origin | 1500 | 4300 Y |
| | $dE_Y$, $dN_Y$ = | 929 | 1019 Y |
| 4. | From the formulae listed for BEGA $dE_M$, $dN_M$ = | 859 | 913 M |
| 5. | Add metre working origin | 6300 | 59000 M |
| | Results | 7159 | 59913 M |
| 6. | Approximate reference to use on BEGA 1:250,000 metric edition (units: thousands of metres) | 716 | 991 |
| | or Cooma 1:100,000 map (units: hundreds of metres) | 15(9) | 91(3)M |

Brackets are used in the lower result of step 6 to indicate that the digits they enclose have a standard error of about ±300 metres due to the inherent imprecision of scaling from a 1:250,000 map.

The Table setting out the data and conversion formulae for thirty four 1:250,000 quadrangles commences overleaf.

THEORETICAL BASIS OF THE METHOD

In order to provide an arithmetically straightforward basis for converting grid co-ordinates from A.S.G. to A.M.G. it appeared essential to be able to employ the elementary rules of the transformation of plane co-ordinates. It was reported above that the largest area over which this was practicable with acceptable standard errors was found to be the standard 1:250,000 map quadrange one degree of latitude by one and a half degrees of longitude in extent.

Because the two co-ordinate grids did not have common central meridians the differing amounts of enlargement, dependent on distance from respective central meridians, had first to be allowed for using the appropriate scale factors before the co-ordinate grids could be imagined superimposed. All yard measurements were converted to metres for the purpose. The tendency of the central meridians to increase in distance apart as one proceeds north means that the two co-ordinate grids thus adjusted are not parallel, but diverge by an angle which is the algebraic sum of their respective convergences. The divergence is not constant but changes slowly with increasing distance from the origins. It is this aspect that imposes the principal limitation on the area over which a simple rule may be applied. Lastly, the origins (whether taken to be the primary, false or purely local origins) are not coincident.

On the basis, then, that the conditions have been established under which the two grid systems may be treated as locally co-planar we may employ the expressions for the transformation of the co-ordinates (x,y) of a point to (x',y') in a second system:

$$x' = (x - \alpha)\cos\theta + (y - \beta)\sin\theta$$
$$y' = -(x - \alpha)\sin\theta + (y - \beta)\cos\theta,$$

where $(\alpha,\beta)$ are the co-ordinates of the origin of the primed system in the unprimed system and $\theta$ = counterclockwise angle of rotation of the primed axes.

The above expressions make it intuitively evident that the grid conversion rules will have the form to the first order:

$$dE_M = kdE_Y\cos D + kdN_Y\sin D - (A\cos D + B\sin D)$$
$$dN_M = kdN_Y\cos D - kdE_Y\sin D + (A\sin D - B\cos D)$$

where: dE and dN are relatively small increments in yard or metre co-ordinates relative to local, convenient origins;

A and B are equivalent to $\alpha$ and $\beta$ above;
D is the angular divergence of the metre grid from the yard grid, measured positive counterclockwise;
k is a coefficient embodying the conversion from yards to metres, and the yard grid and metre grid scale-factors at the centre of the quadrangle:

$$k = \frac{0.9144 \text{ X (AMG scale factor)}}{\text{ASG scale factor}}$$

It is necessary to recall that the Australian Map Grid applies a central scale factor $m_o$ = 0.9996 to the entire projection.

For the preparation of the numerical data set out in the Table local working yard and metre origins were chosen for each 1:250 000 quadrangle located as close as possible to but outside its

TABLE OF DATA FOR CONVERSION OF GRID REFERENCES FROM A.S.G. TO A.M.G.

| 1:250 000 MAP QUADRANGLE | | GRID CONVERSION SCHEME Units: Hundreds of Yards and Metres | | | | |
|---|---|---|---|---|---|---|
| Name | Co-ordinate ranges in thousands of yards | Yard grid (ASG) Working origin | | Conversion formulae for increments | Metre grid (AMG) Working origin | |
| BATHURST | E: 140 to 300 | 1400 | 7900 | $dE_M = 0.9135dE_Y + 0.0352dN_Y + 14.0$ | 6300 | 62300 |
| | N: 790 to 920 | | | $dN_M = 0.9135dN_Y - 0.0352dE_Y + 7.6$ | | |
| | | Published one-inch maps and their yard grid ranges: | | | | |
| | | Bathurst | | E: 2 470 to 2 990; N: 8 590 to 8 910 | | |
| | | Blayney | | E: 1 960 to 2 480; N: 8 280 to 8 600 | | |
| | | Canowindra | | E: 1 450 to 1 970; N: 8 270 to 8 590 | | |
| | | Cowra | | E: 1 460 to 1 980; N: 7 960 to 8 290 | | |
| | | Oberon | | E: 2 480 to 2 990; N: 8 280 to 8 600 | | |
| | | Orange | | E: 1 960 to 2 480; N: 8 580 to 8 900 | | |
| BEGA | E: 150 to 330 | 1500 | 4300 | $dE_M = 0.9134dE_Y + 0.0380dN_Y - 28.3$ | 6300 | 59000 |
| | N: 430 to 560 | | | $dN_M = 0.9134dN_Y - 0.0380dE_Y + 17.7$ | | |
| CANBERRA | E: 150 to 310 | 1500 | 5500 | $dE_M = 0.9135dE_Y + 0.0371dN_Y + 17.3$ | 6300 | 60100 |
| | N: 550 to 680 | | | $dN_M = 0.9135dN_Y - 0.0371dE_Y + 13.0$ | | |
| | | Published one-inch maps and their yard grid ranges: | | | | |
| | | Bimberi East | | E: 1 760 to 2 030; N: 5 850 to 6 160 | | |
| | | Braidwood | | E: 2 500 to 3 010; N: 6 160 to 6 480 | | |
| | | BrindabellaEast | | E: 1 760 to 2 020; N: 6 150 to 6 470 | | |
| | | Canberra | | E: 1 990 to 2 520; N: 6 160 to 6 480 | | |
| | | Lake Bathurst | | E: 2 500 to 3 010; N: 6 470 to 6 790 | | |
| | | Lake George | | E: 2 000 to 2 510; N: 6 460 to 6 780 | | |
| | | Michelago West | | E: 2 010 to 2 270; N: 5 850 to 6 170 | | |
| COFFS HARBOUR | E: 600 to 650 | 6000 | 11600 | $dE_M = 0.9134dE_Y - 0.0162dN_Y - 82.5$ | 5000 | 65700 |
| | N: 1160 to 1290 | | | $dN_M = 0.9134dN_Y + 0.0162dE_Y - 15.2$ | | |
| | | Published one-inch maps and their yard grid ranges: | | | | |
| | | Coffs Harbour | | E: 6 100 to 6 370; N: 12 220 to 12 530 | | |
| | | Nambucca | | E: 6 090 to 6 360; N: 11 910 to 12 230 | | |
| | | Trial Bay | | E: 6 070 to 6 360; N: 11 610 to 11 930 | | |
| | | Woolgoolga | | E: 6 100 to 6 380; N: 12 520 to 12 840 | | |
| COOTAMUNDRA | E: 490 to 660 | 5000 | 6700 | $dE_M = 0.9138dE_Y - 0.0090dN_Y + 0.5$ | 5000 | 61200 |
| | N: 670 to 800 | | | $dN_M = 0.9138dN_Y + 0.0090dE_Y - 5.0$ | | |
| | | Published one-inch maps and their yard grid ranges: | | | | |
| | | Cootamundra | | E: 6 000 to 6 520; N: 7 050 to 7 380 | | |
| | | Junee | | E: 5 490 to 6 010; N: 6 760 to 7 080 | | |
| | | Young | | E: 6 000 to 6 520; N: 7 360 to 7 680 | | |

CONVERSION TABLE (CONTINUED)

| | | | | | | |
|---|---|---|---|---|---|---|
| DORRIGO | E: 450 to 620 | 4500 | 11600 | $dE_M = 0.9138dE_Y - 0.0162dN_Y + 46.7$ | 3500 | 65600 |
| | N: 1160 to 1290 | | | $dN_M = 0.9138dN_Y + 0.0162dE_Y + 60.3$ | | |

Published one-inch maps and their yard grid ranges:

| | |
|---|---|
| Bellbrook | E: 5 560 to 6 100; N: 11 610 to 11 940 |
| Bowra | E: 5 570 to 6 100; N: 11 920 to 12 240 |
| Dorrigo | E: 5 570 to 6 110; N: 12 220 to 12 540 |
| Glenreagh | E: 5 570 to 6 110; N: 12 520 to 12 840 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DUBBO | E: 140 to 300 | 1400 | 9100 | $dE_M = 0.9136dE_Y + 0.0343dN_Y - 43.7$ | 6400 | 63400 |
| | N: 910 to 1050 | | | $dN_M = 0.9136dN_Y - 0.0343dE_Y + 3.1$ | | |

Published one-inch maps and their yard grid ranges:

| | |
|---|---|
| Brocklehurst | E: 1 410 to 1 940; N: 10 090 to 10 410 |
| Dubbo | E: 1 420 to 1 950; N: 9 770 to 10 110 |

| | | | | | | |
|---|---|---|---|---|---|---|
| FORBES | E: 500 to 660 | 5000 | 7900 | $dE_M = 0.9137dE_Y - 0.0088dN_Y - 10.3$ | 5000 | 62300 |
| | N: 790 to 930 | | | $dN_M = 0.9137dN_Y + 0.0088dE_Y - 8.3$ | | |
| GILGANDRA | E: 140 to 300 | 1400 | 10300 | $dE_M = 0.9136dE_Y + 0.0333dN_Y - 2.4$ | 6400 | 64500 |
| | N: 1030 to 1170 | | | $dN_M = 0.9136dN_Y - 0.0333dE_Y - 1.4$ | | |
| GOONDIWINDI | E: 290 to 460 | 2900 | 14000 | $dE_M = 0.9144dE_Y - 0.0152dN_Y + 45.3$ | 2000 | 67800 |
| | N: 1400 to 1530 | | | $dN_M = 0.9144dN_Y + 0.0152dE_Y + 29.5$ | | |
| GOULBURN | E: 140 to 300 | 1400 | 6700 | $dE_M = 0.9135dE_Y + 0.0362dN_Y - 29.5$ | 6300 | 61200 |
| | N: 670 to 800 | | | $dN_M = 0.9135dN_Y - 0.0362dE_Y + 12.2$ | | |

Published one-inch map and its yard grid range:

| | |
|---|---|
| Goulburn | E: 2 490 to 3010; N: 6 760 to 7 090 |

| | | | | | | |
|---|---|---|---|---|---|---|
| GRAFTON | E: 450 to 620 | 4500 | 12800 | $dE_M = 0.9138dE_Y - 0.0157dN_Y + 27.3$ | 3500 | 66800 |
| | N: 1280 to 1410 | | | $dN_M = 0.9138dN_Y + 0.0157dE_Y - 42.7$ | | |

Published one-inch maps and their yard grid ranges:

| | |
|---|---|
| Alice | E: 5 590 to 6 140; N: 13 740 to 14 060 |
| Clive | E: 4 530 to 5 070; N: 13 750 to 14 070 |
| Coaldale | E: 5 590 to 6 130; N: 13 440 to 13 750 |
| Grafton | E: 5 580 to 6 130; N: 13 130 to 13 450 |
| Nymboida | E: 5 580 to 6 120; N: 12 830 to 13 150 |
| Tenterfield | E: 5 060 to 5 600; N: 13 750 to 14 060 |

CONVERSION TABLE (CONTINUED)

| | | | | | | |
|---|---|---|---|---|---|---|
| HASTINGS | E: 450 to 610 | 4500 | 10400 | $dE_M = 0.9138dE_Y - 0.0167dN_Y + 66.8$ | 3500 | 64500 |
| | N: 1040 to 1170 | | | $dN_M = 0.9138dN_Y + 0.0167dE_Y + 63.3$ | | |

Published one-inch maps and their yard grid ranges:

| | | |
|---|---|---|
| Camden Haven | E: 5 550 to 6 080; | N: 10 710 to 11 030 |
| Comboyne | E: 5 030 to 5 560; | N: 10 710 to 11 030 |
| Cowarral | E: 5 030 to 5 570; | N: 11 020 to 11 330 |
| Cundle | E: 5 550 to 5 850; | N: 10 410 to 10 720 |
| Kempsey | E: 5 560 to 6 090; | N: 11 310 to 11 630 |
| Korogoro Point | E: 6 080 to 6 350; | N: 11 310 to 11 620 |
| Mooraback | E: 5 040 to 5 570; | N: 11 320 to 11 640 |
| Port Macquarie | E: 5 550 to 6 090; | N: 11 010 to 11 330 |
| Wingham | E: 5 030 to 5 560; | N: 10 410 to 10 730 |

| | | | | | | |
|---|---|---|---|---|---|---|
| INVERELL | E: 290 to 460 | 2900 | 12800 | $dE_M = 0.9144dE_Y - 0.0157dN_Y + 64.2$ | 2000 | 66700 |
| | N: 1280 to 1410 | | | $dN_M = 0.9144dN_Y + 0.0157dE_Y + 31.7$ | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| JERILDERIE | E: 350 to 500 | 3500 | 5500 | $dE_M = 0.9140dE_Y - 0.0093dN_Y + 40.7$ | 3600 | 60100 |
| | N: 550 to 680 | | | $dN_M = 0.9140dN_Y + 0.0093dEY - 15.7$ | | |

Published one-inch maps and their yard grid ranges:

| | | |
|---|---|---|
| Buraja | E: 4 000 to 4 500; | N: 5 570 to 5 880 |
| Howlong | E: 4 490 to 4 990; | N: 5 560 to 5 880 |
| Tocumwal | E: 3 500 to 4 000; | N: 5 570 to 5 880 |

| | | | | | | |
|---|---|---|---|---|---|---|
| MACLEAN | E: 610 to 670 | 6100 | 12800 | $dE_M = 0.9134dE_Y - 0.0157dN_Y - 10.6$ | 5000 | 66800 |
| | N: 1280 to 1410 | | | $dN_M = 0.9134dN_Y + 0.0157dE_Y - 17.4$ | | |

Published one-inch maps and their yard grid ranges:

| | | |
|---|---|---|
| Bare Point | E: 6 110 to 6 650; | N: 12 820 to 13 140 |
| Brushgrove | E: 6 110 to 6 660; | N: 13 120 to 13 440 |
| Maclean | E: 6 120 to 6 660; | N: 13 430 to 13 750 |
| Woodburn | E: 6 120 to 6 670; | N: 13 730 to 14 050 |

| | | | | | | |
|---|---|---|---|---|---|---|
| MALLACOOTA | E: 150 to 310 | 1500 | 3100 | $dE_M = 0.9134dE_Y + 0.0388dN_Y - 74.9$ | 6300 | 57900 |
| | N: 310 to 440 | | | $dN_M = 0.9134dN_Y - 0.0388dE_Y + 22.2$ | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| MANILLA | E: 290 to 460 | 2900 | 11600 | $dE_M = 0.9144dE_Y - 0.0162dN_Y - 16.3$ | 2100 | 65600 |
| | N: 1160 to 1290 | | | $dN_M = 0.9144dN_Y + 0.0162dE_Y + 34.0$ | | |

Published one-inch map and its yard grid range:

| | | |
|---|---|---|
| Attunga | E: 3 470 to 4 000; | N: 11 630 to 11 950 |

| | | | | | | |
|---|---|---|---|---|---|---|
| MOREE | E: 130 to 300 | 1300 | 12800 | $dE_M = 0.9137dE_Y + 0.0314dN_Y - 11.6$ | 6400 | 66800 |
| | N: 1280 to 1410 | | | $dN_M = 0.9137dN_Y - 0.0314dE_Y - 15.6$ | | |

CONVERSION TABLE (CONTINUED)

| | | | | | | |
|---|---|---|---|---|---|---|
| NARRABRI | E: 130 to 300 | 1300 | 11600 | $dE_M = 0.9137dE_Y + 0.0324dN_Y - 50.5$ | 6400 | 65600 |
| | N: 1160 to 1290 | | | $dN_M = 0.9137dN_Y - 0.0324dE_Y + 88.8$ | | |
| NARRANDERA | E: 340 to 510 | 3400 | 6700 | $dE_M = 0.9140dE_Y - 0.0090dN_Y - 61.9$ | 3600 | 61200 |
| | N: 670 to 800 | | | $dN_M = 0.9140dN_Y + 0.0090dE_Y - 19.6$ | | |
| NARROMINE | E: 500 to 660 | 5000 | 9100 | $dE_M = 0.9137dE_Y - 0.0086dN_Y - 20.8$ | 5000 | 63400 |
| | N: 910 to 1050 | | | $dN_M = 0.9137dN_Y + 0.0086dE_Y - 11.6$ | | |
| NEWCASTLE | E: 450 to 610 | 4500 | 9100 | $dE_M = 0.9138dE_Y - 0.0171dN_Y + 89.0$ | 3500 | 63400 |
| | N: 910 to 1050 | | | $dN_M = 0.9138dNY + 0.0171dE_Y - 24.9$ | | |

Published one-inch maps and their grid ranges:

| | |
|---|---|
| Bulahdelah | E: 5 020 to 5 550; N: 9 800 to 10 120 |
| Dungog | E: 4 510 to 5 040; N: 9 810 to 10 130 |
| Gloucester | E: 4 510 to 5 040; N: 10 110 to 10 430 |
| Krambach | E: 5 030 to 5 550; N: 10 110 to 10 430 |
| Morna Point | E: 5 020 to 5 290; N: 9 200 to 9 520 |
| Newcastle | E: 4 510 to 5 030; N: 9 200 to 9 520 |
| Paterson | E: 4 510 to 5 030; N: 9 510 to 9 820 |
| Port Stephens | E: 5 020 to 5 540; N: 9 500 to 9 820 |
| Seal Rocks | E: 5 540 to 5 800; N: 9 800 to 10 120 |
| Tuncurry | E: 5 540 to 5 810; N: 10 100 to 10 420 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ST. GEORGE | E: 130 to 300 | 1300 | 14000 | $dE_M = 0.9137dE_Y + 0.0305dN_Y + 26.1$ | 6400 | 67900 |
| | N: 1400 to 1530 | | | $dN_M = 0.9137dN_Y - 0.0305dE_Y - 19.9$ | | |
| SINGLETON | E: 290 to 460 | 2900 | 9200 | $dE_M = 0.9144dE_Y - 0.0172dN_Y + 24.4$ | 2100 | 63400 |
| | N: 920 to 1050 | | | $dN_M = 0.9144dN_Y + 0.0172dE_Y + 38.6$ | | |

Published one-inch maps and their yard grid ranges:

| | |
|---|---|
| Camberwell | E: 4 000 to 4 520; N: 9 800 to 10 130 |
| Cessnock | E: 4 000 to 4 520; N: 9 210 to 9 520 |
| Doyles Creek | E: 3 480 to 4 000; N: 9 510 to 9 820 |
| Mount Yengo | E: 3 480 to 4 000; N: 9 210 to 9 520 |
| Muswellbrook | E: 3 480 to 4 000; N: 9 800 to 10 130 |
| Scone | E: 3 480 to 4 000; N: 10 120 to 10 430 |
| Singleton | E: 4 000 to 4 520; N: 9 510 to 9 820 |
| Woolooma | E: 4 000 to 4 520; N: 10 120 to 10 430 |

| | | | | | | |
|---|---|---|---|---|---|---|
| SYDNEY | E: 290 to 480 | 2900 | 7900 | $dE_M = 0.9143dE_Y - 0.0176dN_Y + 47.3$ | 2100 | 62300 |
| | N: 790 to 930 | | | $dN_M = 0.9143dN_Y + 0.0176dE_Y - 50.3$ | | |

Published one-inch maps and their yard grid ranges:

| | |
|---|---|
| Broken Bay | E: 4 000 to 4 500; N: 8 300 to 8 610 |
| Glen Alice | E: 2 980 to 3 490; N: 8 900 to 9 220 |
| Gosford and Norahville | E: 4 000 to 4 600; N: 8 600 to 8 910 |

CONVERSION TABLE (CONTINUED)

| | | | | | | |
|---|---|---|---|---|---|---|
| SYDNEY (Continued) | | | | Jenolan E: 2 980 to 3 500; N: 7 990 to 8 310 | | |
| | | | | Katoomba E: 2 980 to 3 500; N: 8 290 to 8 610 | | |
| | | | | Lake Macquarie E: 4 500 to 4 750; N: 8 900 to 9 220 | | |
| | | | | Liverpool E: 3 490 to 4 000; N: 7 990 to 8 300 | | |
| | | | | Mellong E: 3 480 to 4 000; N: 8 900 to 9 220 | | |
| | | | | Morisset E: 4 000 to 4 510; N: 8 900 to 9 220 | | |
| | | | | St. Albans E: 3 490 to 4 000; N: 8 600 to 8 910 | | |
| | | | | Sydney E: 4 000 to 4 510; N: 7 990 to 8 310 | | |
| | | | | Wallerawang E: 2 980 to 3 500; N: 8 600 to 8 910 | | |
| | | | | Windsor E: 3 490 to 4 000; N: 8 300 to 8 600 | | |
| TALLANGATTA | E: 490 to 650 | 4900 | 4300 | $dE_M = 0.9138dE_Y - 0.0095dN_Y - 68.3$ | 5000 | 59000 |
| | N: 430 to 560 | | | $dN_M = 0.9138dN_Y + 0.0095dE_Y + 0.7$ | | |
| | | | | Published one-inch map and its yard grid range: | | |
| | | | | Kosciusko E: 5 960 to 6 460; N: 4 930 to 5 250 | | |
| TAMWORTH | E: 290 to 460 | 2900 | 10400 | $dE_M = 0.9144dE_Y - 0.0167dN_Y + 3.7$ | 2100 | 64500 |
| | N: 1040 to 1170 | | | $dN_M = 0.9144dN_Y + 0.0167dE_Y + 36.3$ | | |
| | | | | Published one-inch map and its yard grid range: | | |
| | | | | Tamworth E: 3 470 to 4 000; N: 11 330 to 11 640 | | |
| TWEED HEADS | E: 610 to 730 | 6100 | 14000 | $dE_M = 0.9133dE_Y - 0.0152dN_Y - 29.6$ | 5000 | 67800 |
| | N: 1400 to 1530 | | | $dN_M = 0.9133dN_Y + 0.0152dE_Y + 78.9$ | | |
| | | | | Published one-inch maps and their yard grid ranges: | | |
| | | | | Ballina E: 6 660 to 6 940; N: 14 020 to 14 340 | | |
| | | | | Byron Bay E: 6 670 to 6 950; N: 14 330 to 14 650 | | |
| | | | | Lismore E: 6 130 to 6 680; N: 14 020 to 14 350 | | |
| | | | | Murwillumbah E: 6 140 to 6 690; N: 14 640 to 14 960 | | |
| | | | | Nimbin E: 6 130 to 6 680; N: 14 330 to 14 660 | | |
| | | | | Norries Head E: 6 670 to 6 950; N: 14 630 to 14 950 | | |
| | | | | Springbrook E: 6 140 to 6 690; N: 14 940 to 15 260 | | |
| | | | | Tweed Heads E: 6 680 to 6 960; N: 14 930 to 15 250 | | |
| ULLADULLA | E: 300 to 450 | 3000 | 5500 | $dE_M = 0.9143dE_Y - 0.0185dN_Y + 82.8$ | 2200 | 60100 |
| | N: 550 to 680 | | | $dN_M = 0.9143dN_Y + 0.0185dE_Y - 43.6$ | | |
| | | | | Published one-inch maps and their yard grid ranges: | | |
| | | | | Jervis Bay E: 3 500 to 4 000; N: 6 480 to 6 790 | | |
| | | | | Moruya E: 3 010 to 3 260; N: 5 560 to 5 880 | | |
| | | | | Tianjara E: 3 000 to 3 510; N: 6 460 to 6 790 | | |
| WAGGA WAGGA | E: 490 to 650 | 4900 | 5500 | $dE_M = 0.9138dE_Y - 0.0093dN_Y - 79.7$ | 5000 | 60100 |
| | N: 550 to 680 | | | $dN_M = 0.9138dN_Y + 0.0093dE_Y - 2.6$ | | |
| | | | | Published one-inch map and its yard grid range: | | |
| | | | | Wagga Wagga E: 4 990 to 5 500; N: 6 470 to 6 790 | | |

CONVERSION TABLE (CONTINUED)

| | | | | | | |
|---|---|---|---|---|---|---|
| WANGARATTA | E: 350 to 500 | 3500 | 4300 | $dE_M = 0.9140dE_Y - 0.0095dN_Y + 52.1$ | 3600 | 59000 |
| | N: 430 to 560 | | | $dN_M = 0.9140dN_Y + 0.0095dE_Y - 12.7$ | | |

Published one-inch map and its yard grid range:

| | | |
|---|---|---|
| Albury | E: 4 490 to 4 990: | N: 5 260 to 5 580 |

| | | | | | | |
|---|---|---|---|---|---|---|
| WARWICK | E: 450 to 620 | 4500 | 14000 | $dE_M = 0.9138dE_Y - 0.0152dN_Y + 8.4$ | 3500 | 67800 |
| | N: 1400 to 1530 | | | $dN_M = 0.9138dN_Y + 0.0152dE_Y + 54.2$ | | |

Published one-inch maps and their yard grid ranges:

| | | |
|---|---|---|
| Bonalbo | E: 5 600 to 6 150; | N: 14 340 to 14 660 |
| Drake | E: 5 060 to 5 610; | N: 14 050 to 14 370 |
| Mount Lindesay | E: 5 600 to 6 150; | N: 14 650 to 14 970 |
| Tabulam | E: 5 590 to 6 140; | N: 14 040 to 14 360 |
| Wallangarra | E: 4 530 to 5 070; | N: 14 050 to 14 370 |

| | | | | | | |
|---|---|---|---|---|---|---|
| WOLLONGONG | E: 290 to 450 | 2900 | 6700 | $dE_M = 0.9143dE_Y - 0.0181dN_Y - 30.9$ | 2200 | 61200 |
| | N: 670 to 800 | | | $dN_M = 0.9143dN_Y + 0.0181dE_Y - 48.0$ | | |

Published one-inch maps and their yard grid ranges:

| | | |
|---|---|---|
| Camden | E: 3 490 to 4 000; | N: 7 690 to 8 000 |
| Kiama | E: 3 490 to 4 000; | N: 7 080 to 7 400 |
| Mittagong | E: 2 990 to 3 500; | N: 7 380 to 7 700 |
| Moss Vale | E: 2 990 to 3 500; | N: 7 080 to 7 400 |
| Nowra | E: 3 490 to 4 000; | N: 6 780 to 7 090 |
| Port Hacking | E: 4 000 to 4 510; | N: 7 690 to 8 000 |
| Wollongong | E: 3 490 to 4 000; | N: 7 390 to 7 700 |
| Yalwal | E: 3 000 to 3 510; | N: 6 780 to 7 090 |

south-western corner. Whole-number values were taken to simplify the user's arithmetic. Numerical evaluation of the constants for the formulae was based on tables of the two projections. This procedure would have been relatively straightforward but for the need to adjust for the varying shift of meridians and parallels imposed by the change of reference spheroid from the Clarke 1858 spheroid employed by the Army yard grid to the Australian National Spheroid employed by the Australian Map Grid.

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Department of Geology and Geophysics,
The University of Sydney, N.S.W., 2006.

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# NOTICE TO AUTHORS

A "Style Guide to Authors" is available from the Honorary Secretary, Royal Society of New South Wales, 35 Clarence Street, Sydney, NSW 2000, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarized below.

## GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

Offset printing with "Typeset-it-Yourself" preparation of a master manuscript suitable for photography is used in the production of the Journal. Authors will be supplied with a set of special format paper. An IBM Selectric (Golf Ball) typewriter with ADJUTANT 12 typeface must be used. Biological and reference material are shown in *Light Italic.* Symbol 12 has most type required for mathematical expressions and formulae. Detailed instructions for the typist are included in the Style Guide.

## PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on heavy bond A4 paper. A second copy of both text and illustrations is required for office use. This may be a clear carbon or photographic copy. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgments and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; name(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgments; references; appendices; name of Institution/Organisation where work carried out/or private address as applicable; date manuscript received by the Society. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the Australian Code of Stratigraphic Nomenclature (revised fourth edition) and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra. The letter of approval should be submitted with the manuscript.

*Abstract.* A brief but fully informative abstract must be provided.

*Tables* should be adjusted for size to fit the format paper of the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

*Illustrations.* When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to ½ size) must be clearly stated.

*Note:* There is a reduction of 30% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. the scale of maps or diagrams must be given in bar form.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper (no negative is required).

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*References* are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow the preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by author and then chronologically by date.

Abbreviations of titles of periodicals shall be in accordance with the International Standard Organization IS04 "International Code for the Abbreviation of Titles of Periodicals" and International Standard Organization IS0833 "International List of Periodical Title Word Abbreviations" and as amended.

*Appendices* should be placed at the end of the paper, be numbered in Arabic numerals, have a caption and be referred to in the text.

*Reprints.* An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

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